LIGO Laboratory / LIGO Scientific Collaboration

LIGO-T1000308-v1 *ADVANCED LIGO* 6/29/10

AOS: Stray Light Control (SLC)--
Output Faraday Isolator
FDR Responses

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Abstract

This document presents responses to the review committee for the Final Design of the Output Faraday Isolator (OFI), a component of the AOS Stray Light Control subsystem for aLIGO.

1 Issues to address at the FDR.

1.1 Scatter light noise analysis. Please lead us through your scattered light noise analysis, being explicit about the inputs you are using in the model. In particular:

6.2. The scattered light noise analysis given here has a large overlap with what is given in T1000190-v2. This makes it unclear as to what the real source is meant to be. Either: include everything that is in T1000190 in T1000181, and remove the former from the document set; or, include just the summary plot in T1000181, and refer to T1000190 for details

1.1.1 Scattered Light Requirement

A DARM signal is obtained when the differential arm length is modulated as a result of a gravity wave strain. The DARM signal was calculated in reference, T060073-00 Transfer Functions of Injected Noise, and is defined by the following expression:

$$V_{signal} := DARM \cdot L \cdot h_{SRD} \cdot \sqrt{P_0}$$

Where L is the arm length, h_{SRD} is the minimum SRD gravity wave strain spectral density requirement, P_0 is the input laser power into the IFO, and DARM is the signal transfer function.

In a similar manner, an apparent signal (scattered light noise) occurs when a scattered light field with a phase shift is injected into the IFO at some particular location, e.g. through the back of the ETM mirror. The scattered light noise is defined by the following expression:

$$V_{noise} := SNXXX \cdot \delta_{SN} \cdot \sqrt{P_{SNi}}$$

P_{SNi} is the scattered light power injected into the IFO mode, δ_{SN} is the phase shift of the injected field, and SNXXX is the noise transfer function for that particular injection location.

The phase shift spectral density of the injected field due to the motion of the scattering surface is given by

$$\delta_{SNi} := \frac{4 \cdot \pi \cdot x_s}{\lambda}$$

where x_s is the spectral density of the longitudinal motion of the scattering surface.

In general, the different scattering sources are not coherent and must be added in quadrature. The requirement for total scattered light displacement noise can be stated with the following inequality:

$$\sqrt{\sum_{i=1}^{n} \left(\frac{SNXXX}{DARM} \cdot \frac{4 \cdot \pi \cdot x_s}{\lambda} \cdot \sqrt{\frac{P_{SNi}}{P_0}} \right)^2} < \frac{1}{10} \cdot L \cdot h_{SRD}$$

The SNXXX/DARM scattered light noise transfer functions for various injection locations within the IFO were calculated by Hiro and are shown in Figure 1: Scattered Light Noise Transfer Functions.

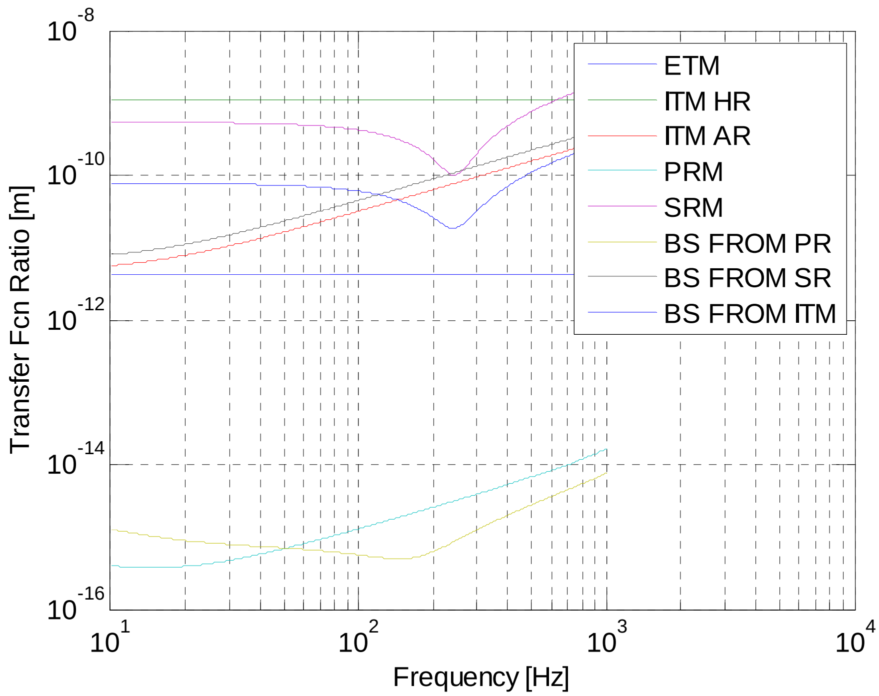

Figure 1: Scattered Light Noise Transfer Functions

1.1.2 OFI Scattered Light Displacement Noise Calculations

The power incident on the Faraday isolator is given by

$$P_{FIin} := P_0 \cdot G_{AS}$$

G_{AS} is the dark port signal ratio.

The light power scattered into the IFO from the five surfaces before the Faraday rotator magnet is given by

$$P_{farads} := 5 \cdot P_{farad} \cdot BRDF_{farad} \cdot \frac{w_{ifo}^2}{w_{rc}^2} \cdot \Delta_{ifo}$$

The scattering surface has the seismic motion of the HAM requirement, attenuated by the motion transfer function of the Output Faraday Isolator suspension.

The scattered light is injected into the SRM mirror, and the appropriate scattered light noise transfer function is 'SRM'. The displacement noise (m/rt Hz) is

$$DN_{faradsifo} := TF_{sr} \cdot \left(\frac{P_{farads}}{P_{psl}} \right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k \cdot faradisolreq$$

1.1.3 BRDF of Faraday Surfaces

Fix whatever errors might have resulted from using a surface roughness for the isolator crystal of 20-40 nm, rather than the correct value of 2-4 angstroms

The 20-40nm statement was an error in the text only and did effect the scattered light noise calculations.

The TGG crystal and the wedge surfaces have specified surface roughness < 0.40 nm, which is considered to be a “super polished surface.” The TGG crystal surface is inclined at 0.5 deg, and the input wedge plate surfaces will be inclined by approximately 0.5 deg to avoid a glint into the IFO. The surface roughness of the Brewster’s angle prisms was not measured.

Do you really use the CSIRO pathfinder BRDF? If so, why is this appropriate?

No scatter data is available for the TGG crystal at 1.0 deg with respect to the incident direction. However, the scatter from the superpolished S/N 2 pathfinder optic by CSIRO is representative of the TGG crystal. The BRDF at a scatter angle of 1.0 deg was calculated from the measured BRDF data of S/N 2 pathfinder optic to be 5.6E-4 sr^-1; see T1000147.

The measured BRDF for backscatter from a super polished surface at 56 deg incidence angle is approximately 1E-6 sr^-1; see T080064-00 Controlling Light Scatter in Advanced LIGO—we will assume that the Brewster’s angle prisms have a conservative BRDF 5 E-4 sr^-1.

State what you are using for BRDF of the surfaces and why (there are several values given in the documentation, and it is not clear what value is used for a given calculation).

Therefore, we will assume an average BRDF = 5E-4 sr^-1 for the 5 optical surfaces of the Faraday Isolator.

1.1.4 HAM ISI Seismic Motion

- Evaluate the noise not only for the current HAM ISI performance, but also for the ISI noise requirement level.

Evaluate the noise assuming that the isolation for a given DOF bottoms out at a value of 40 dB at higher frequencies

The seismic motion of the HAM ISI optical table at LLO in the six DOF is described in T0900285-v1 and is shown below.

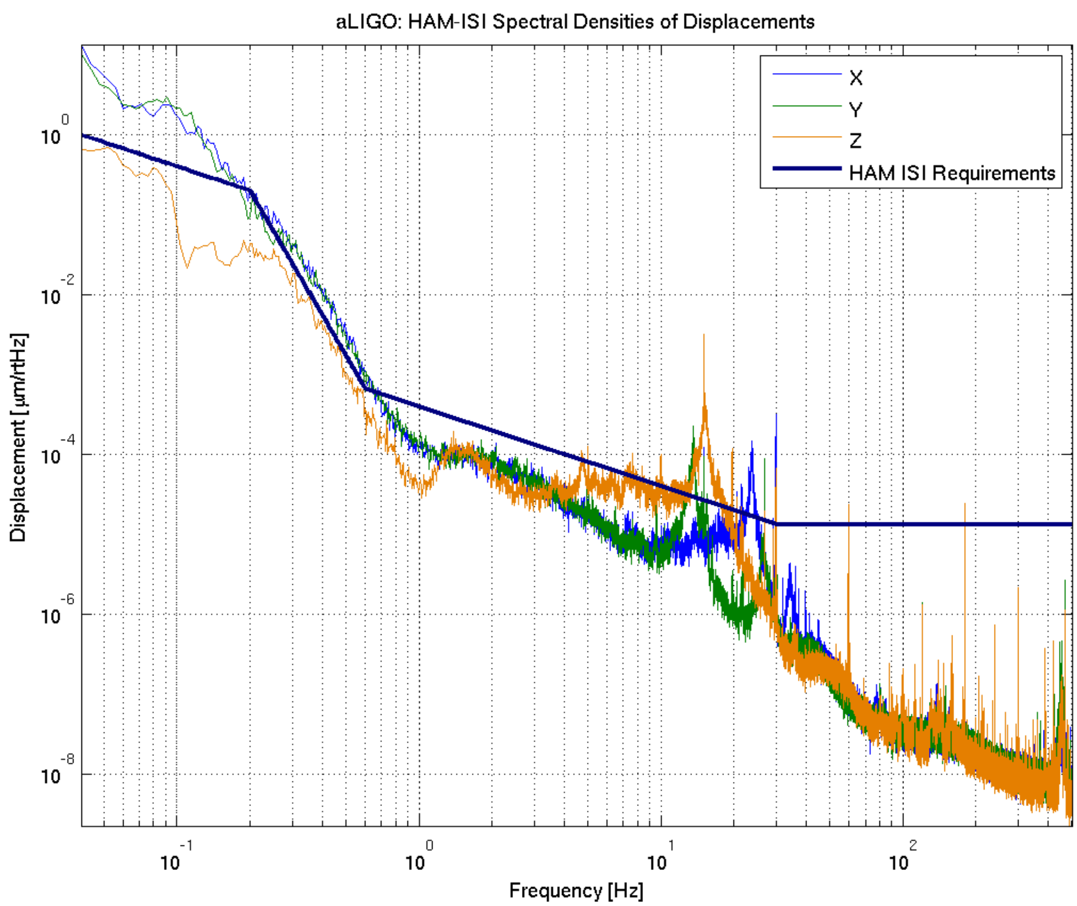

Figure 2: HAM optics table Seismic Motion, Displacement DOFs

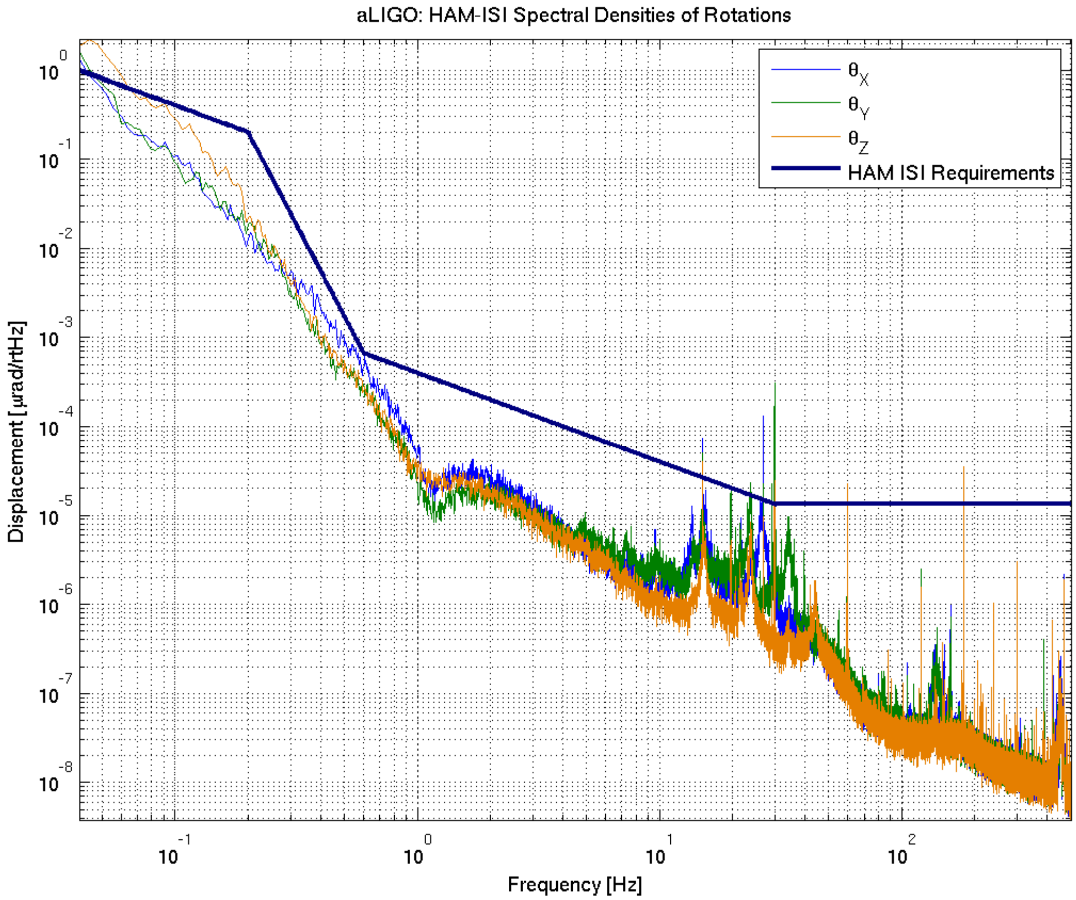

Figure 3: HAM optics table Seismic Motion, Rotational DOF

1.1.5 Motion along the Beam Direction

The optical surfaces of the OFI will scatter light back toward the antisymmetric port of the IFO with varying amounts of displacement noise depending upon the motion of the OFI.

The Output Faraday Isolator has four calcite prism surfaces and one TGG crystal surface on the entrance side. These surfaces are oriented horizontally and will couple X-motion and yaw motion to displacement along the beam direction.

The input wedges have both a horizontal wedge and a vertical component that will also couple pitch motion and Z-motion into motion along the beam direction. For the purpose of this analysis, the input wedge angles were assumed to be horizontal.

The light scattered by the additional surfaces beyond the Faraday rotator magnet will be attenuated by the reverse transmissivity of the Faraday Isolator (T < 0.001) and will be ignored.

1.1.6 Seismic Attenuation Transfer Functions

A new prototype was built, OFIS-Proto2, to test the double wire suspension. This differs from the previous one in the connection of the blades to the payload. Each of the two blades connects to the payload table with two clamped wires which form an upside-down "V".

So far, OFIS-Proto2 has been characterized only looking at its frequency modes. According to current policy of AOS suspensions characterization and validation, no transmissibility measurements will be done.

Measurements of the suspension modes are reported in the following table.

Mode	X Pendulum	TZ Yaw mode	Y Pendulum	Z Bounce Mode	TX Pitch Mode
Frequency [Hz]	0.65	1.04	0.63	1.55	0.62

Mode	Blades X direction	Blades Z direction
Frequency [Hz]	24.6, 78.46 24.77, 78.38	64.35

The measured vertical bounce mode was used to set the vertical blade stiffness in the model. The pitch mode frequency from the model, which depends directly on the blades stiffness, matched quite well the measured value within a few hundreds of a Hertz.

Internal modes of the blades were not modeled. For the OFI scattering contribution we assumed a maximum attenuation factor of 40 dB as requested by the reviewers. Resonance quality factors were set to about ~30 using viscous damping relative to ground to account for the eddy current damper.

Only the modeled transfer functions that contribute to the scattering are shown below.

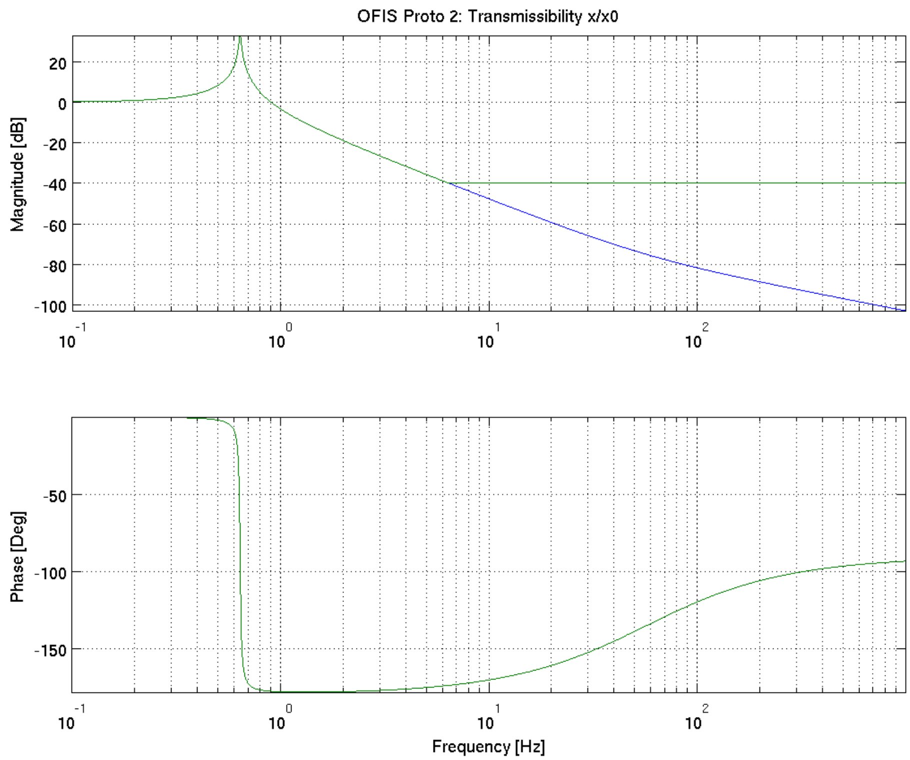

Figure 4: Modeled Output Faraday Isolator SUS transmissibility orthogonal to beam axis.

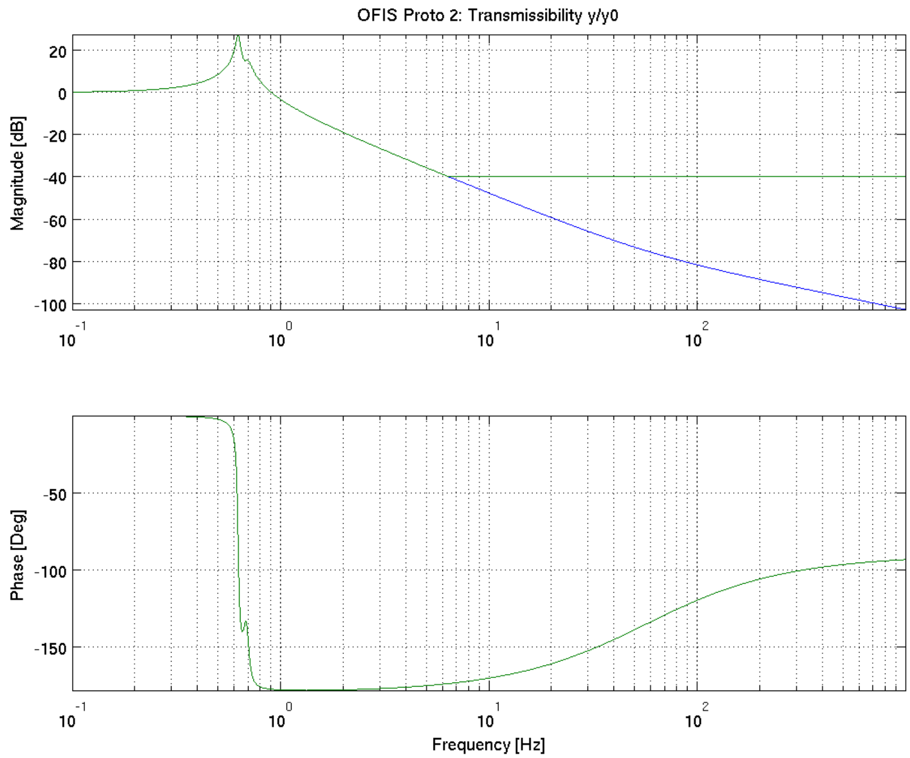

Figure 5: Modeled Output Faraday Isolator SUS transmissibility along beam axis

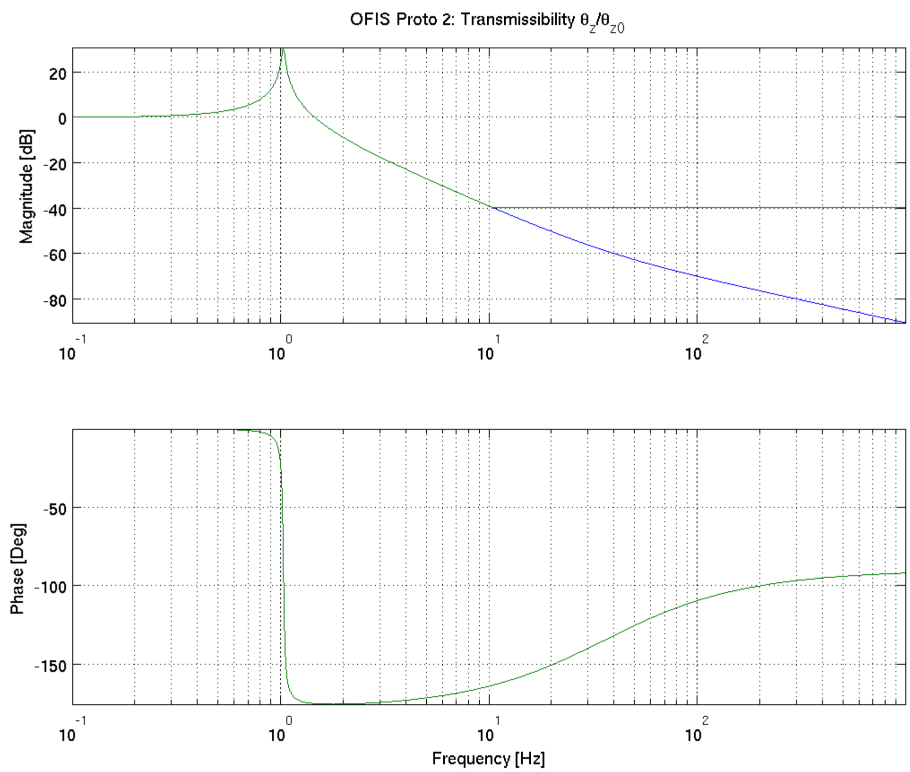

Figure 6: Modeled Output Faraday Isolator SUS transmissibility in the z vertical axis

1.1.7 Scattered Light Displacement Noise of Output Faraday Isolator

The Seismic motion amplitude of each DOF at the OFI was estimated by attenuating the measured HAM-ISI seismic motion with the measured transmissibilities of the OFI suspension prototype. The component of this residual seismic motion along the OFI optical axis was used to determine the back-scattered light displacement noise. See T1000190-v1.

The displacement along the OFI optical axis caused by the angular DOFs was calculated by considering the relative coordinates of the OFI optics elements with respect to the rotational axis of the OFI suspension and of the HAM-ISI. The HAM-ISI rotational axes are assumed to go through the geometric center of the HAM-ISI optical table. The OFI suspension rotational axes go through the geometric center of the suspended rectangular platform.

Because of the assumption that all the wedge angles are horizontal, there is no coupling with DOFs that generate vertical translation of the OFI´s optics faces. The coupling caused by the wedges is therefore maximized in the horizontal DOFs that produce a translation along the OFI beam axis.

State what you are using for geometrical coupling factors.

The coupling depends on the location of the optical surfaces on the suspended platform.

The two figures below are two examples that show how one excitation couples into the beam direction. The other coupling mechanism were calculated using the same type of analysis.

In Figure 7, H_x and H_y are the OFI suspension trasmissibility along x and y directions. The coefficient α is the coupling factor due to the wedge angle of the optical element.

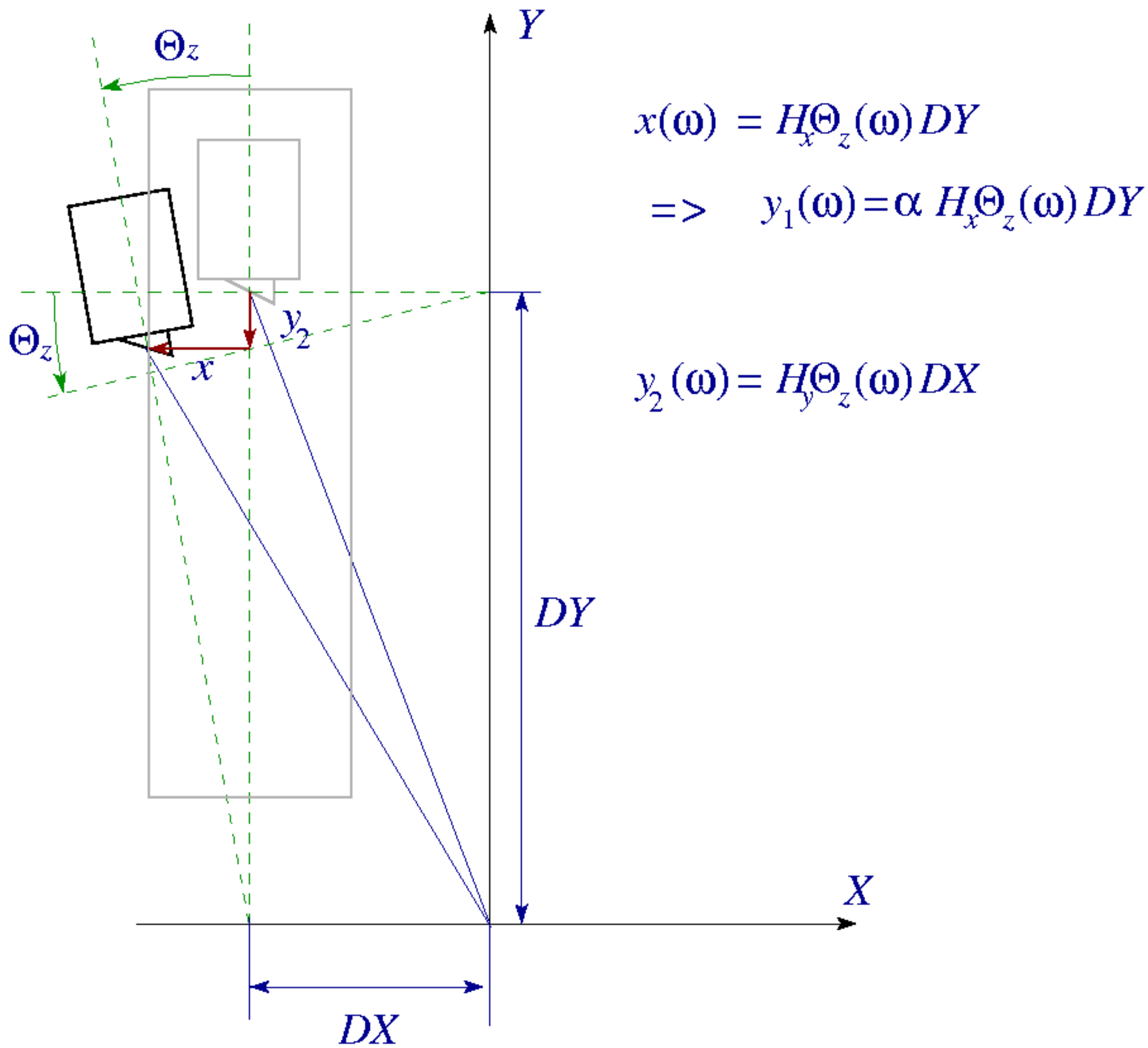

Figure 7: HAM-ISI yaw Θ_z coupling y_1, and y_2 along the beam direction due to the translation of the OFIS suspension.

In Figure 8, $H_{\theta z}$ is the OFI suspension trasmissibility about z axis. The coefficient α is the coupling factor due to the wedge angle of the optical element.

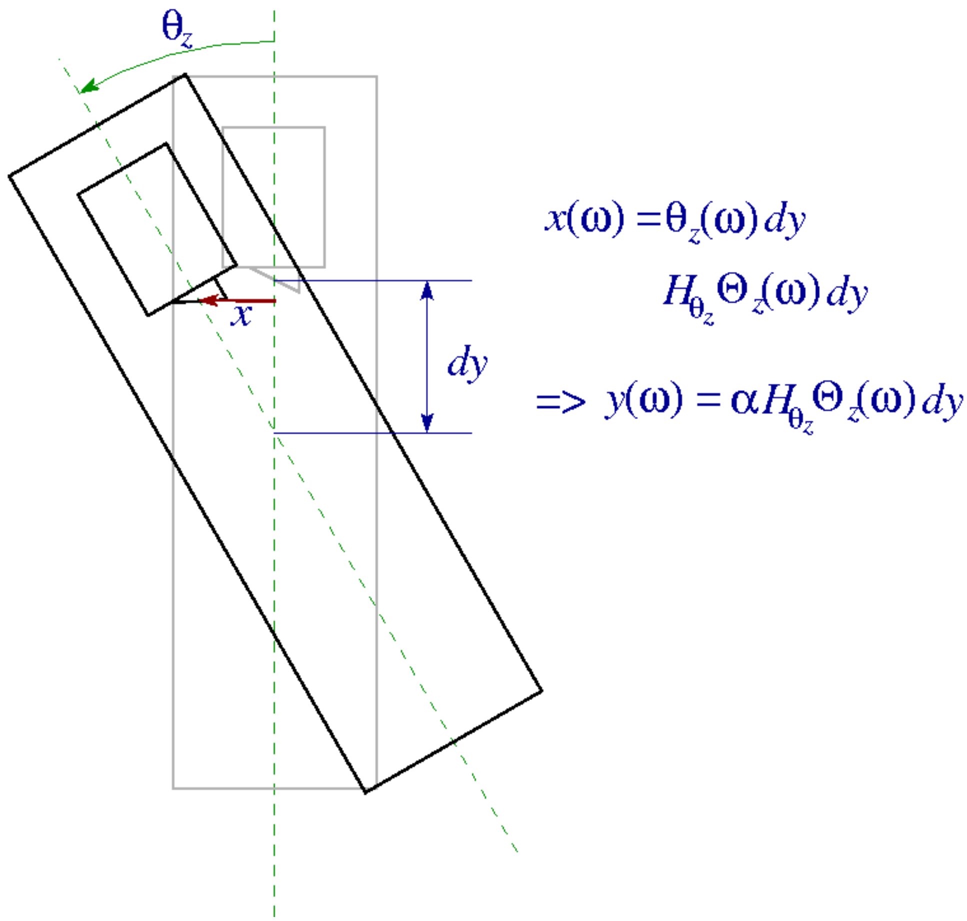

Figure 8: HAM-ISI yaw Θz coupling y along the beam direction due rotation of the OFIS suspension.

The calculated coupling factors for each degree of freedom are shown in Table 1.

Table 1: Calculated Coupling Factors for each Degree of Freedom

Optical System	HAM-ISI DOF	Excited DOF OFI Sus	Coupling Mechanism	Coupling Factor α
Prism Doublet				
	X	*x*	Horizontal wedge angle	1.48
	Y	*y*	Direct	1
	Θ_X	*y*	Direct	0.5

Optical System	HAM-ISI DOF	Excited DOF OFI Sus	Coupling Mechanism	Coupling Factor α
	Θ_Y	x	Horizontal wedge angle	0.74
	Θ_Z	x	Horizontal wedge angle	0.5
	Θ_Z	y	Direct	0.37
	Θ_Y	θ_y	Horizontal wedge angle	0.11
	Θ_Z	θ_z	Arm lever + Horizontal wedge angle	0.18
Faraday Isolator				
	X	X	Horizontal wedge angle	'0.009
	Y	Y	Direct	1
	Θ_X	Y	Direct	0.5
	Θ_Y	X	Horizontal wedge angle	'0.004
	Θ_Z	X	Horizontal wedge angle	'0.004
	Θ_Z	Y	Direct	0.37
	Θ_Y	θ_y	Horizontal wedge angle	0.11
	Θ_Z	θ_z	Arm lever + Horizontal wedge angle	'0.0004

Evaluate the noise not only for the current HAM ISI performance, but also for the ISI noise requirement level.

Evaluate the noise assuming that the isolation for a given DOF bottoms out at a value of 40 dB at higher frequencies.

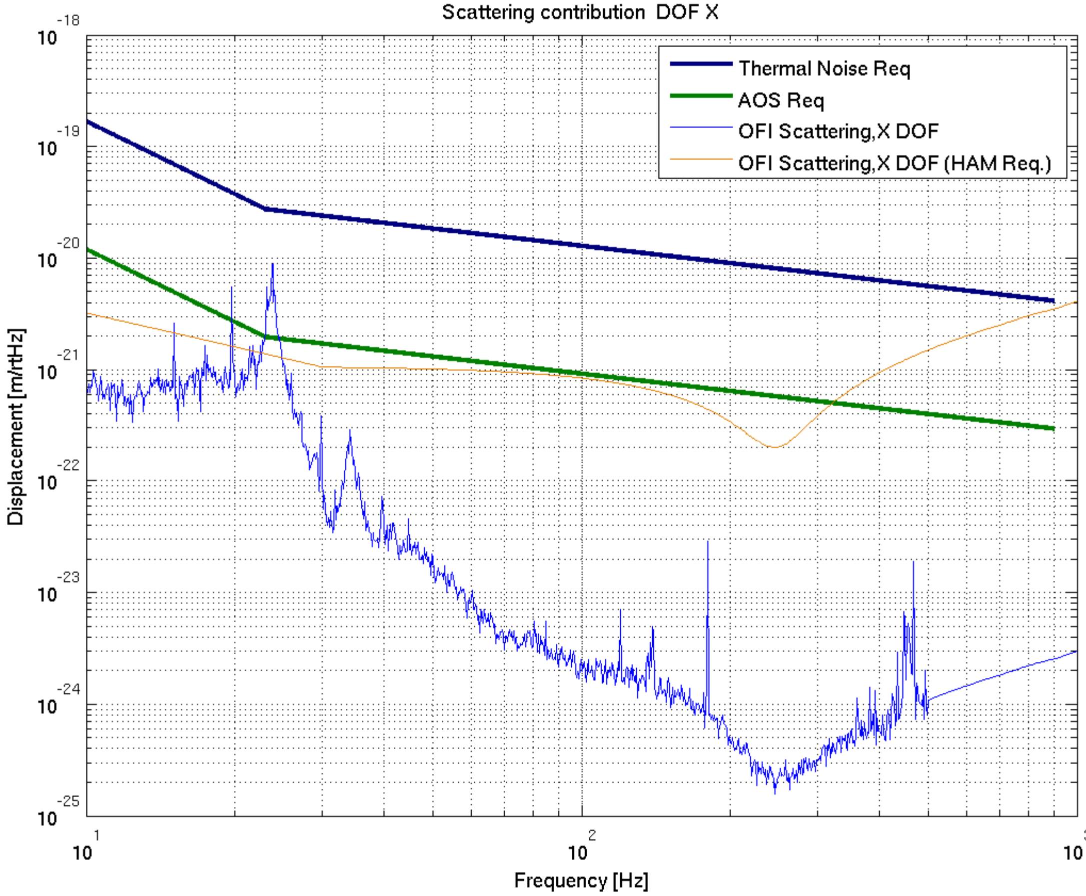

Figure 9: OFI Scattered Light Displacement Noise, due to HAM-ISI X DOF

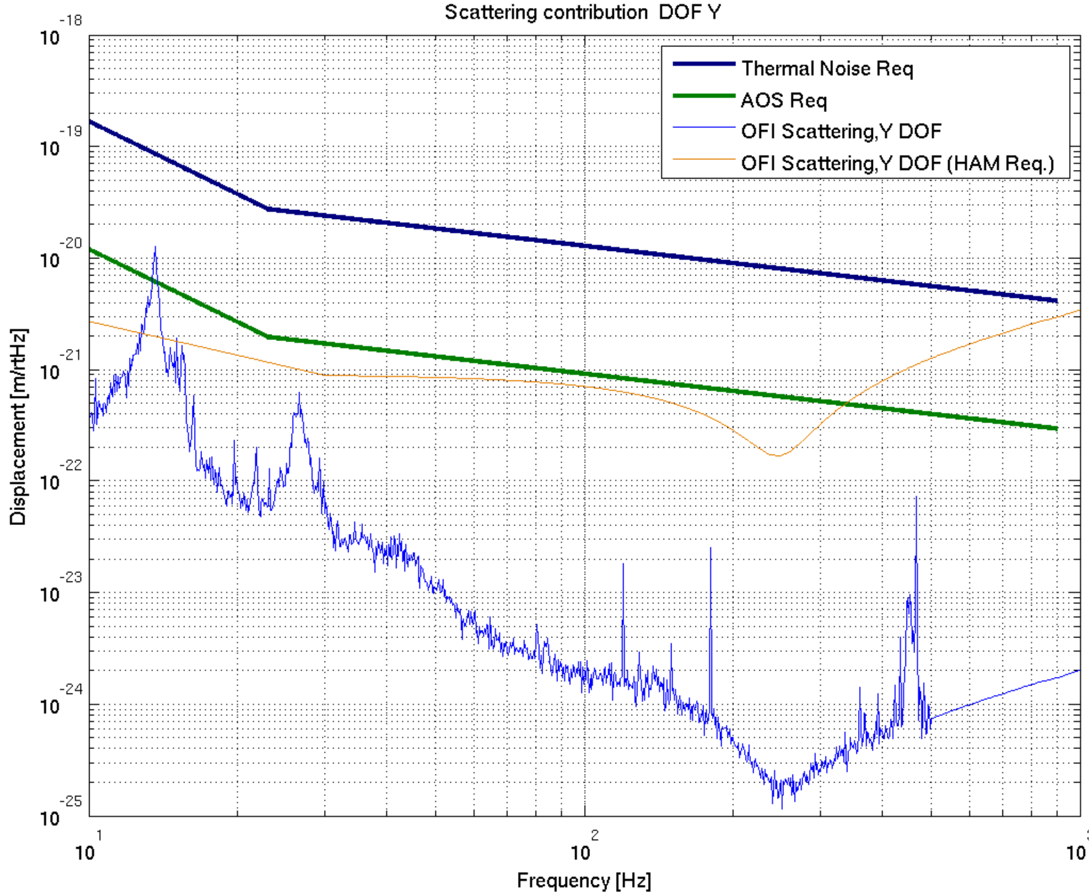

Figure 10: OFI Scattered Light Displacement Noise, due to HAM-ISI Y DOF

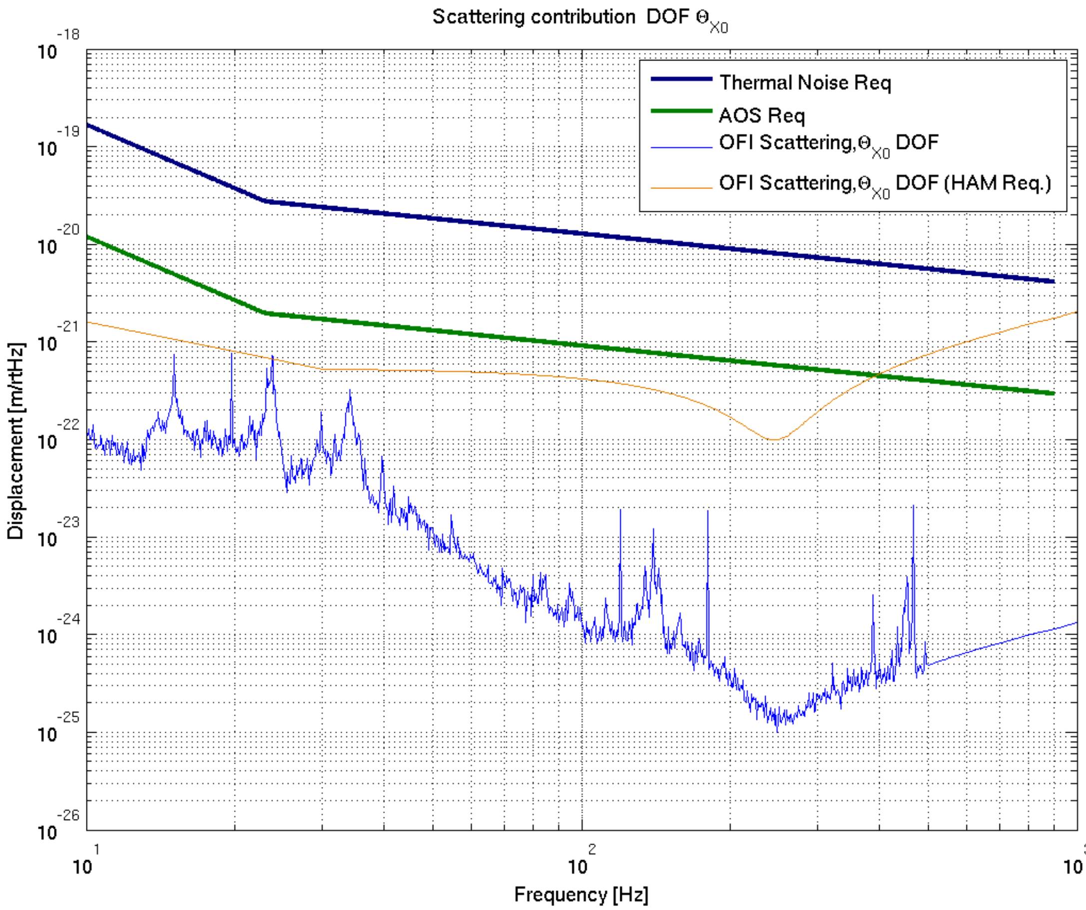

Figure 11: OFI Scattered Light Displacement Noise due to HAM-ISI Θ_x DOF

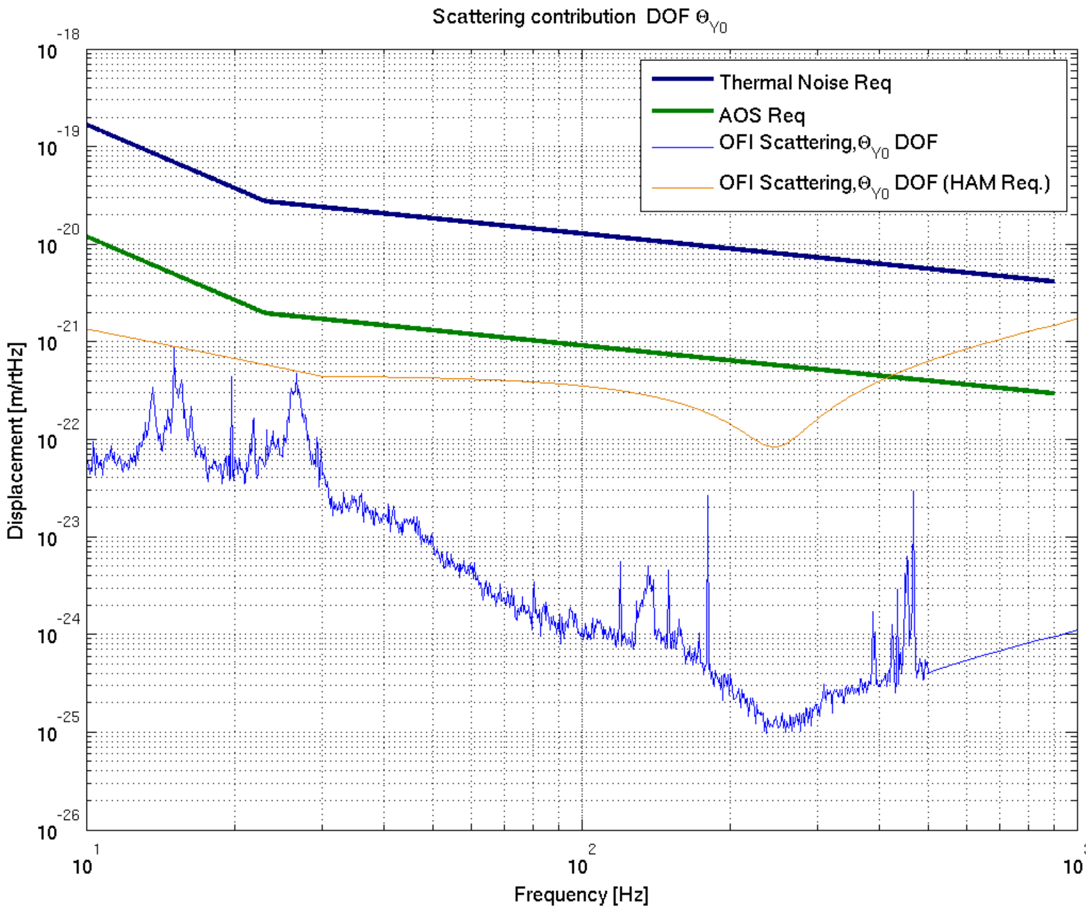

Figure 12: OFI Scattered Light Displacement Noise, HAM-ISI HAM-ISI Θ_Y DOF

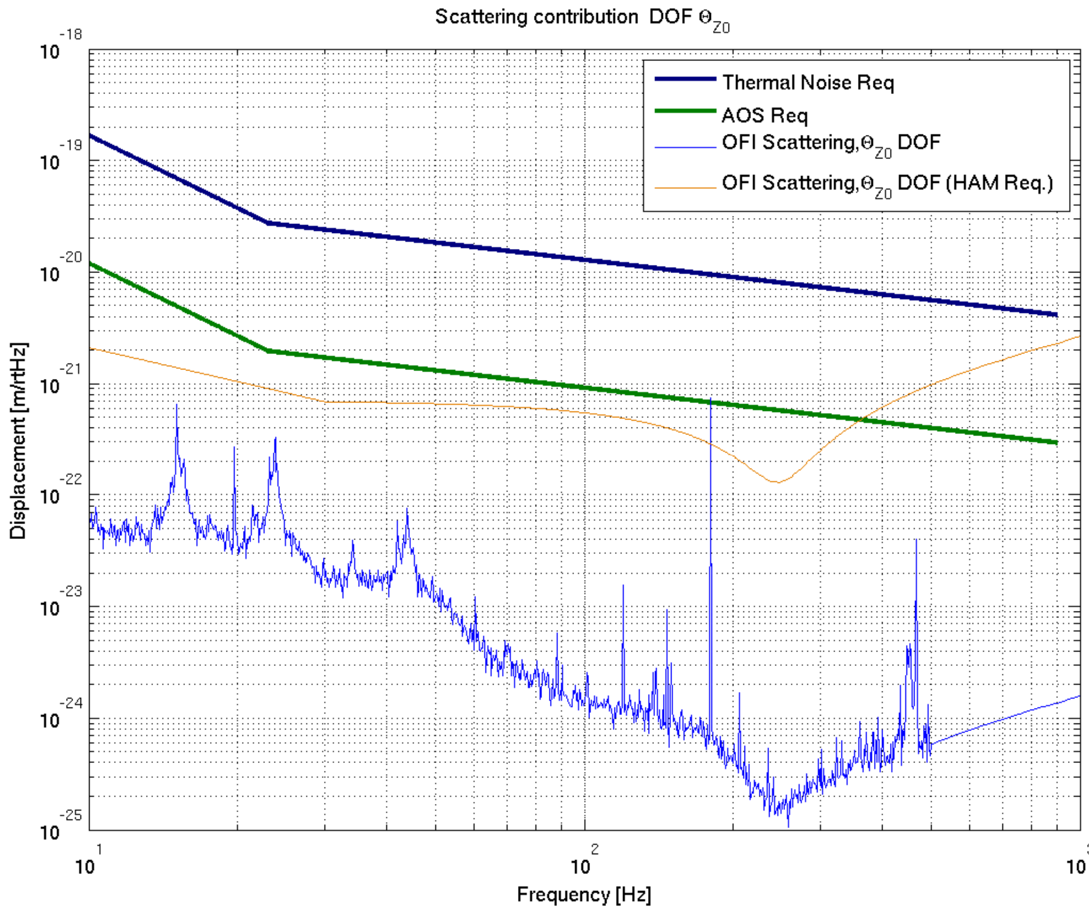

Figure 13: OFI Scattered Light Displacement Noise, HAM-ISI Θ_Z DOF

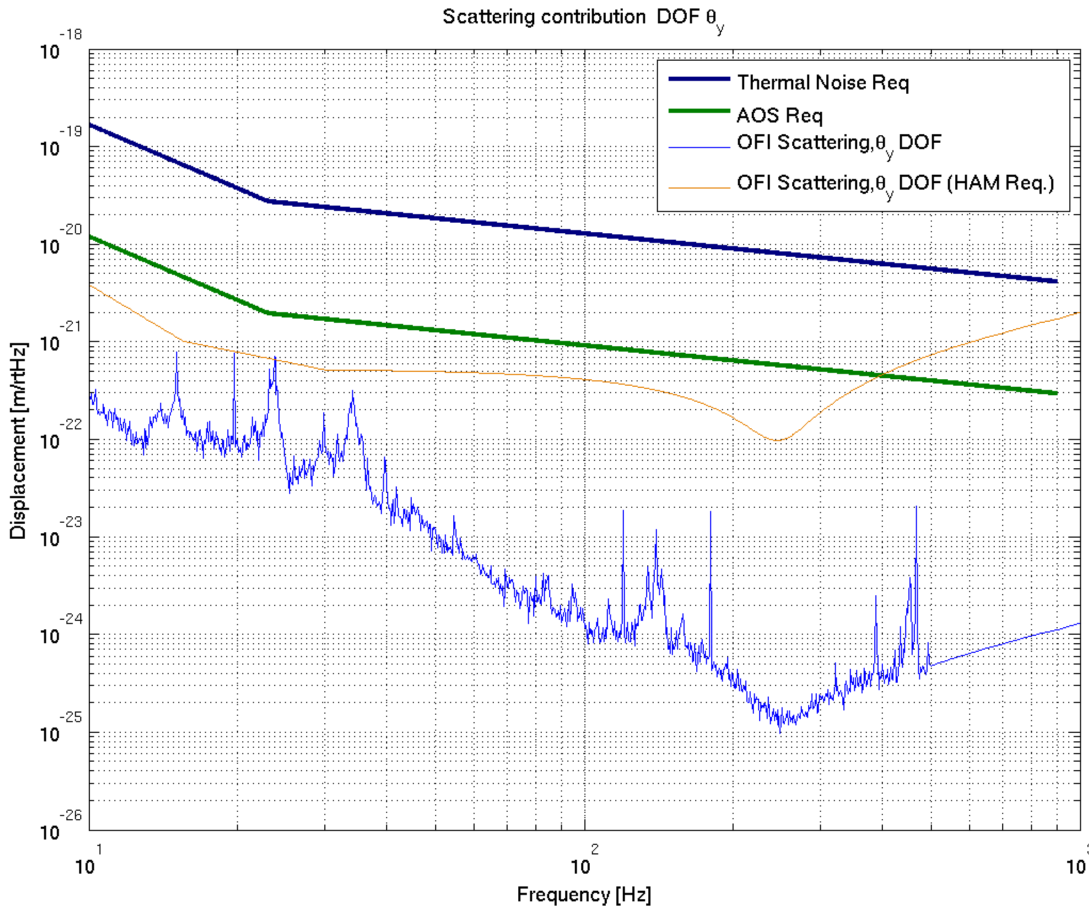

Figure 14: OFI Scattered Light Displacement Noise, OFI Suspension Θ_y DOF.

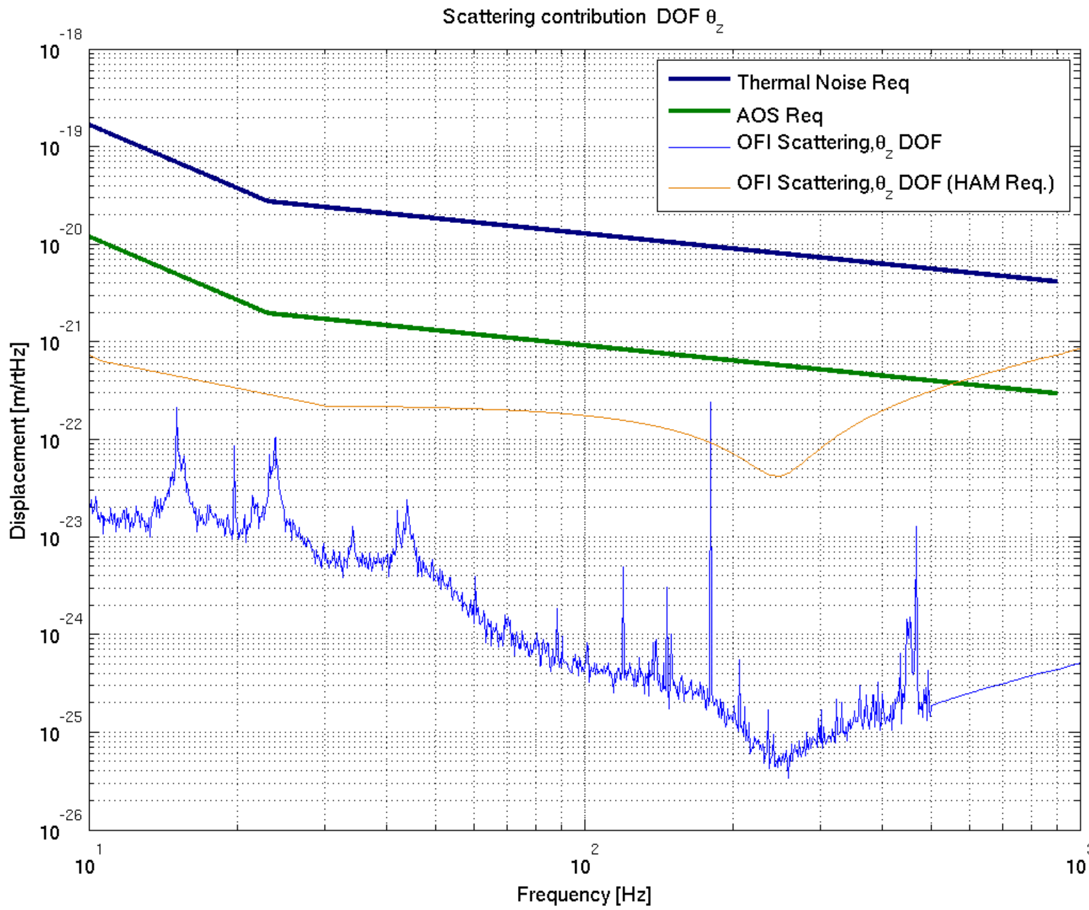

Figure 15: OFI Scattered Light Displacement Noise, OFI Suspension Θ_Z DOF.

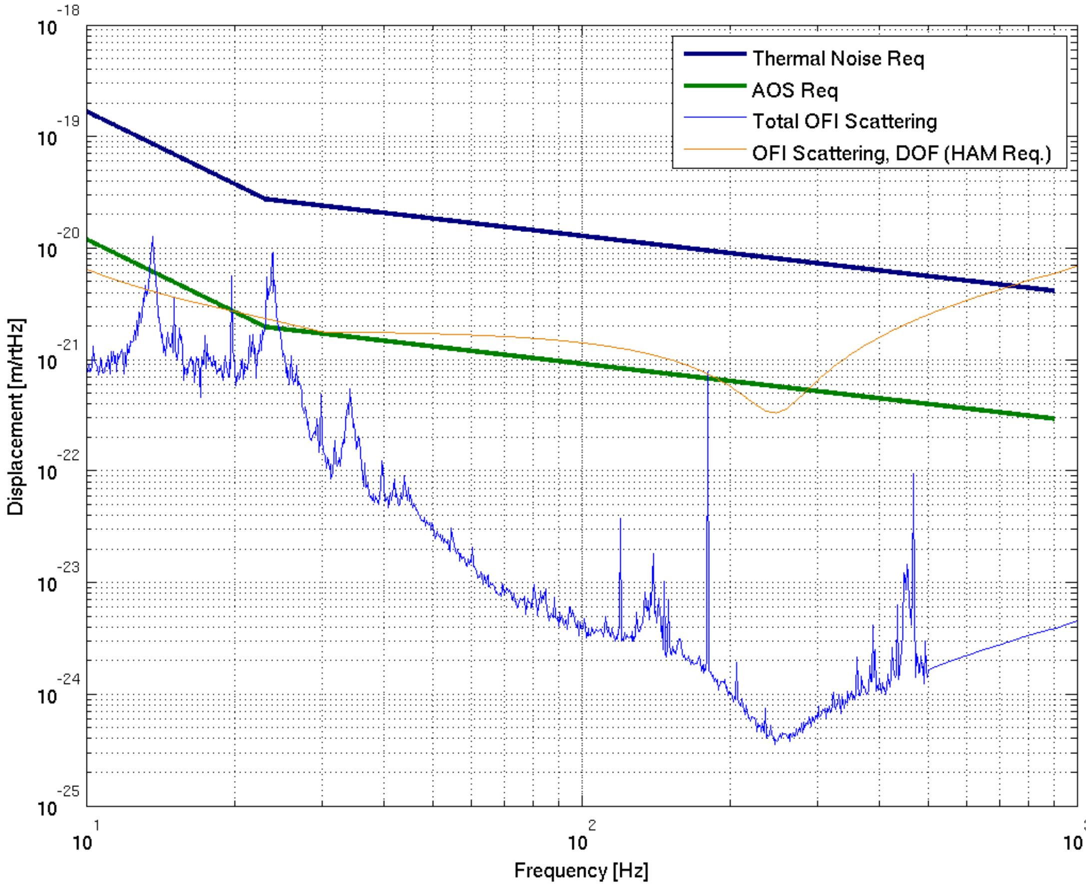

Figure 16: Total OFI Scattered Light Displacement Noise

1.1.8 Scattered Light Parameters

The IFO parameters that were used for the design of the OFI are listed in Table 2.

Table 2: IFO parameter values used for scattered light calculation

PARAMETER	VALUE
beam_radius_Faraday;	2.10E-03
IFO_beamwaist;	1.15E-02
lambda;	1.064E-06
IFO_solid_angle;	2.72E-09
dark_port_power;	1.35E-01
BRDF_Faraday	4.9200e-004

2 Review the motivation for the input variable wedge pair (why is it necessary?). What is the beam angle exiting the SRM, including tolerances?

2.1 Input Variable Wedge

The OFI variable input wedge angle device will be eliminated, and the suspended OFI optical table will be tilted accordingly to match the tilted beam axis.

The beam angle exiting the SRM AR surface varies between 0.5 and 0.64 deg for the maximum and minimum wedge angles of the ITM for all three IFOs.

The beam height at the ISC chamber will vary by approximately 20 mm for the H1 and L1 IFOs. The height is constant for H2 because the FMs are adjusted to maintain the same height at the SRM.

Table 3: Output Beam Angle from SRM vs ITM Wedge Angle

IFO	ITM wedge angle, deg	SRM beam angle, deg	Height at OFI, mm	Height at ISC chamber, mm
H1,L1	0.07	-0.64	-106.3	-122.1
H1,L1	0.1	-0.50	-129.4	-141.9
H2	0.07	-0.51	-152	-172
H2	0.1	-0.51	-152	-172

3 Glint Spoiler

Review the motivation for the glint spoiler. Given the angle on the isolator crystal face, shouldn't it be possible to control (suitably dump) all surface reflections?

The glint spoiler will be eliminated, since all surfaces are tilted > 0.5 degrees.

Also, indicate all first surface reflections from the OFI components and show how they are dumped.

The first surface reflection from the Brewster's prisms are caught on the near normal surfaces of the AR coated black glass beam dumps shown in Figure 17.

The first surface reflection from the TGG crystal will be caught and dumped on the WAMCB4 Manifold Baffle, as shown in Figure 18.

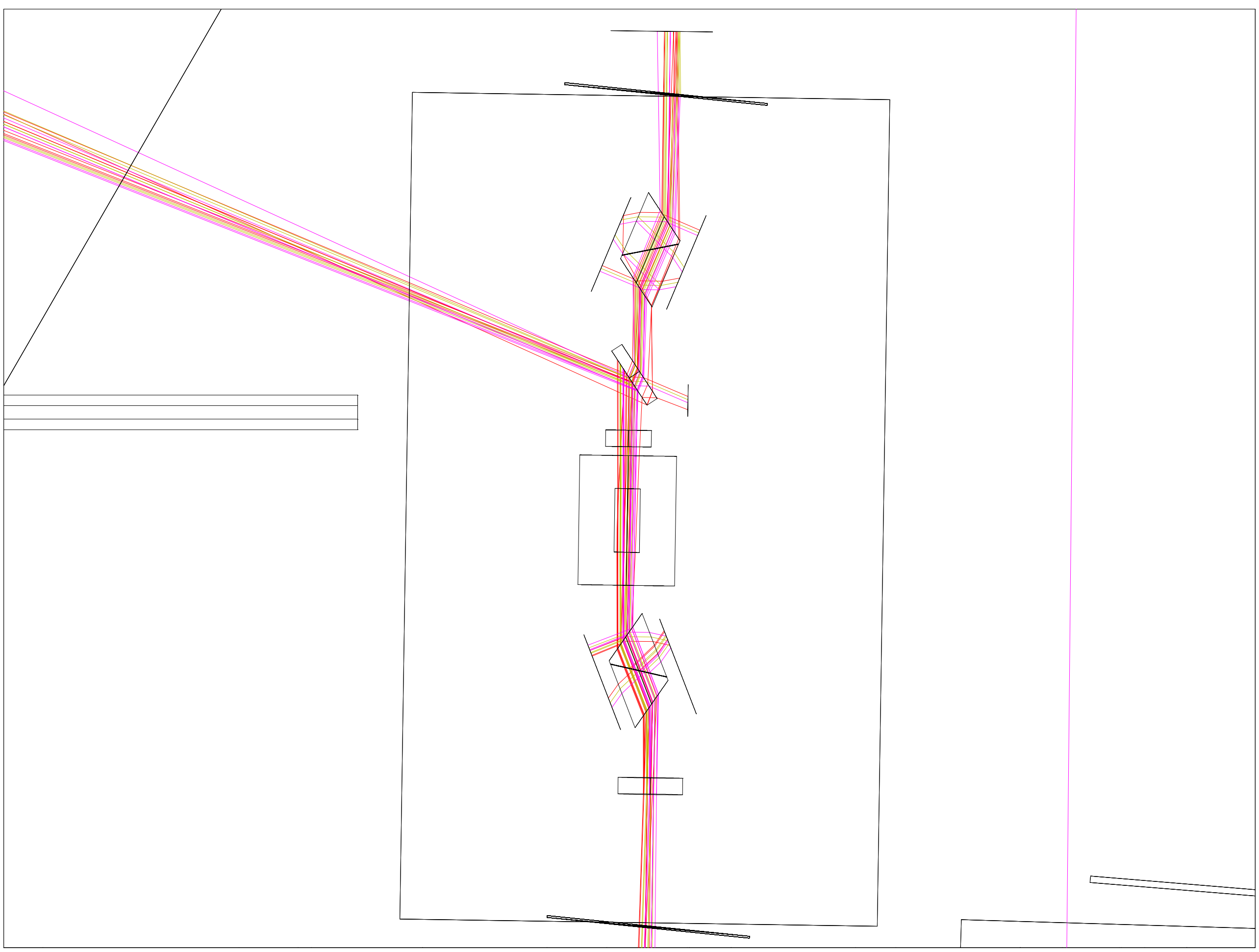

Figure 17: Surface Reflections from OFI Dumped on Black Glass Plates

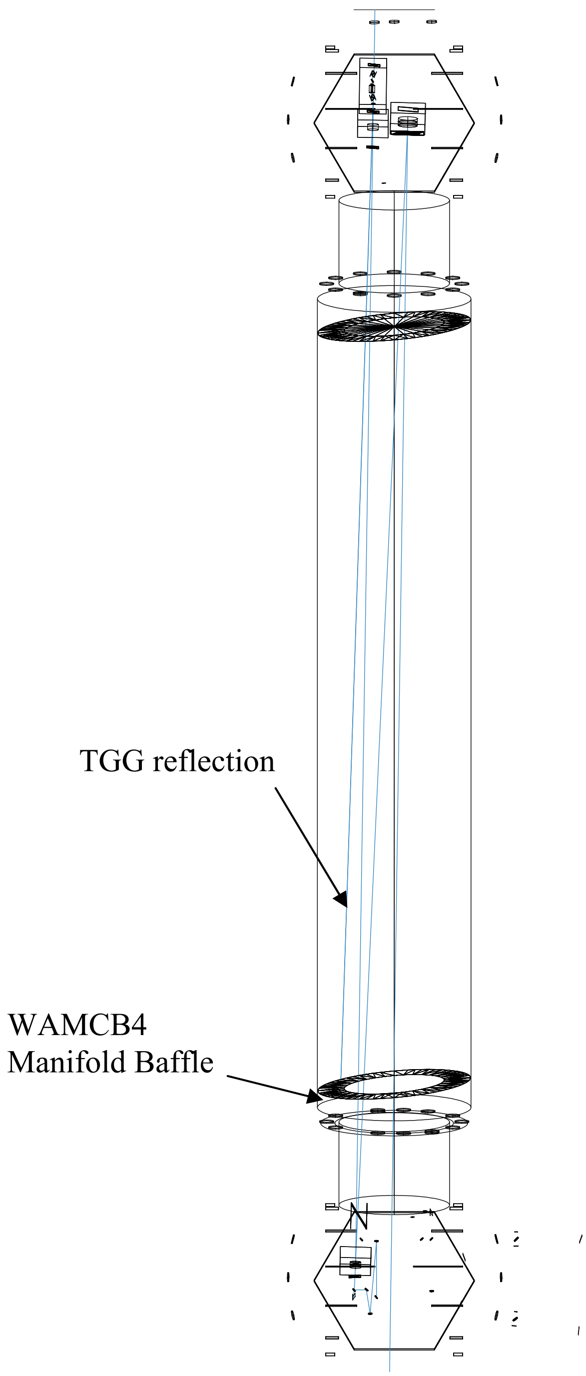

Figure 18: Reflected Beam from OFI TGG Crystal Dumped on WAMCB4 Manifold Baffle

4 Wavefront Distortion

Wavefront distortion. The spec of < 1 lambda sounds pretty loose. Why is this believed to be adequate? Please consider the impact on mode-matching to the fundamental mode of the output mode cleaner. The rotator spec indicates that you received interferograms of the transmitted wavefront through the crystals, so your analysis could use these maps to analyze how much power is lost from the TEM00 mode.

The measured wavefront maps were used to determine the aberration of the iLIGO OFI shown in Table 4. In addition, the spare TGG crystal is shown.

Table 4: Component Wavefront Aberrations for iLIGO OFI

	Waves of Aberration per Device						
Device	**1**	**2**	**3**	**4**	**5**	**6**	**ave**
TGG Crystal (@633 nm)	0.312	0.215	0.274	0.199	0.47		0..294
Brewster prism pair (@633 nm)	0.177	0.173	0.196	0.224	0.175	0.229	0.196
half-wave plate (spec @633 nm)							0.25
total ave distortion (@633 nm)							0.47
total ave distortion (@1064 nm)							0.28

note: total distortion calculation using square root of sum of squares, 1 TGG + 2 Brewster prism pairs + 1 half-wave plate

We assume that the wavefront aberration is totally astigmatic. An overlap integral was calculated to determine the overlap of the aberrated wavefront with the TEM00 mode. The mismatched portion was considered to be lost to the OMC cavity. The OFI beam parameters are shown in Table 2.

The results of the coupling loss calculation are shown in Figure 19: Lost Power in OMC due to Aberrations on the Input Beam. Less than 0.4% coupling loss will occur with the actual aberrations of the OFI components.

Table 5: OFI Beam Parameters

IFO	OFI Aperture, mm	Beam Diameter, mm	Diameter ratio
H1, L1	20	4.2	4.8
H2	20	5.6	3.6

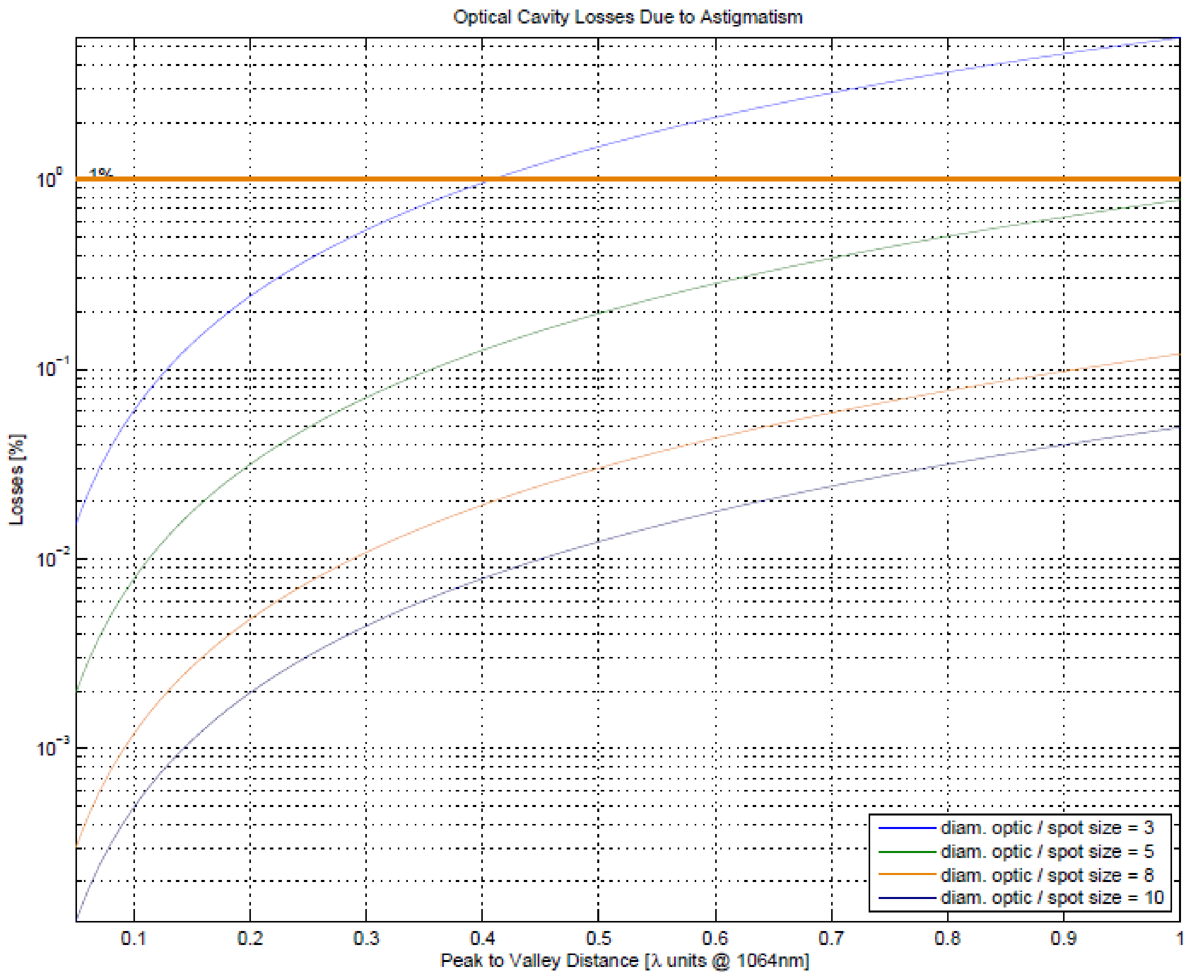

Figure 19: Lost Power in OMC due to Aberrations on the Input Beam

4.1 Rotator specification (E1000116).

Rather than an actual specification, this document appears to be a listing of the specs from a particular rotator vendor (EOT). Or was this document actually sent to EOT and other vendors for quotation? Please clarify.

The OFI optical components will be reused from iLIGO—those components were purchased from EOT as specified by LIGO in the Faraday Isolator specification, E980131. The rotator specification for the spare OFI optics, E1000116, is identical to the original iLIGO specification except for the 0.5 deg wedge of the TGG crystal, which was 1.0 deg. The 0.5 deg wedge is standard for EOT, and an analysis of the glint from a 0.5 wedge meets the LIGO stray light requirement.

Also please clarify the materials used in the rotator (sections 3.5 and 3.6 are rather confusing); i.e., present to us the materials list used in the EOT rotators.

Material list:

1020-1026 DOM Steel, with electroless nickel plate, 0.0005 in thick

Fasteners, 8-18 Stainless steel

6061-T6 aluminiuim

Terbium Gallium Garnet

Neodymiuim iron boride

It is not clear from the spec whether the faces are parallel, or whether there is 1 deg between them; please clarify – also, compare to the crystals in the existing rotators (ie, is this the same?).

The spec will be modified to specify that the faces are parallel.

5 General optical design questions.

5.1 Half Wave Plate

What are the specs for the half-wave plates?

Surface flatness	< ¼ wave @ 633 nm
Surface quality	40-20 scratch dig
Retardation error	< 5 nm
Reflectivity per surface	< 0.25 %
Clear aperture diameter	22 mm
configuration	Zero order crystalline quartz, air-spaced

5.2 Input Variable Wedge

What are the specs for the wedge plates?
N/A.

5.3 Squeezed Light Input Beam Splitter

What are the specs for the squeezed light beam coupler?

Specifications	
Angle of Incidence	56°±3°.*
Clear Aperture	≥ 85% of central diameter
cw	1 MW/cm^2 @ 1064 nm
Pulsed	20 J/cm^2, 20 nsec, 20 Hz @ 1064 nm
T_p/T_s	λ ≥ 527 nm: 200:1 λ = 248 nm, 266 nm, and 355 nm: 100:1
Transmission Efficiency	λ ≥ 527 nm: 95% λ = 355 nm: 90% λ = 248 nm or 266 nm: 85%
Transmitted Wavefront Error	λ/8 at 633 nm
Chamfer	0.35 mm @ 45° (typical)
Diameter	φ+0/-0.25 mm
Optical Material	λ < 425 nm: UV-grade fused silica λ ≥ 425 nm: BK7 glass
Surface Figure	λ/10 at 633 nm before coating
Surface Quality	10-5 scratch and dig
Thickness	t±0.25 mm
Wedge	≤ 5 arc min

- We suggest working with the IO folks on the specs and procurement of the thin film polarizer (TFP) for the squeezed beam coupler. Also, given a high-quality TFP, would it be possible to eliminate the output Brewster calcite polarizer from the design?

The extinction ratio of the KLC Brewster calcite polarizers used in the iLIGO OFI is specified as 2E-5. Can a TFP have an extinction ratio that high?

- Aperture: show a beam-on view of the assembly, with apertures marked. What is the limiting aperture and how is the beam outside this aperture baffled?

The diameter of the TGG crystal is 20.7 mm. The cover plate of the TGG crystal is 20 mm diameter. The aperture of the half wave plate is 22 mm diameter. The aperture of the Brewster calcite prisms is 27 x 20 mm.
The limiting physical aperture of the OFI is the 19 mm diameter of black glass input aperture plate. The black glass will dissipate the beam outside of the 19 mm diameter clear aperture.

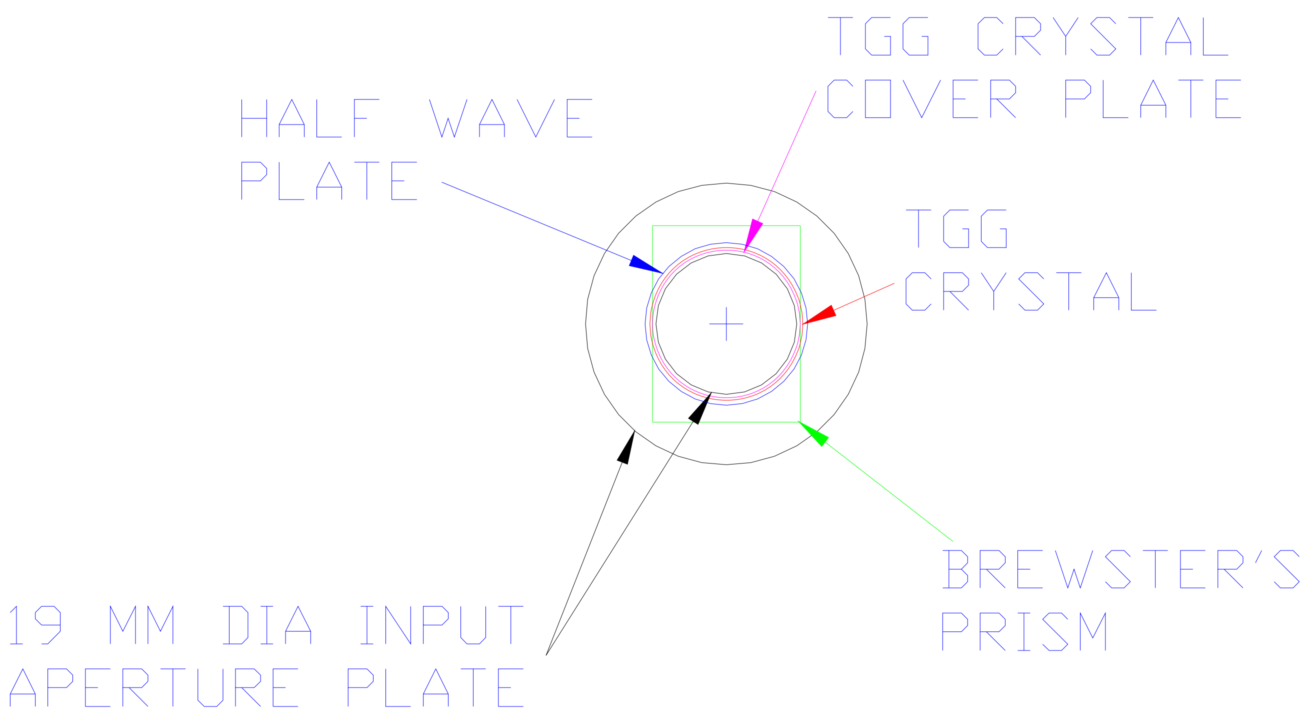

Figure 20: Limiting Aperture of OFI

6 Questions on the suspension design.

The committee would like to understand why the suspension design is as it is -- please review with us the considerations that went into the design, as it is shown in Fig. 2 of T1000181-v1 (not including the support structure, which we understand is a copy of the OMC suspension structure).

Note: after the review committee read the posted documents and met to discuss them, we were made aware that the suspension design might be significantly changed from what has been shown to us. Clearly this needs to be clarified to the committee.

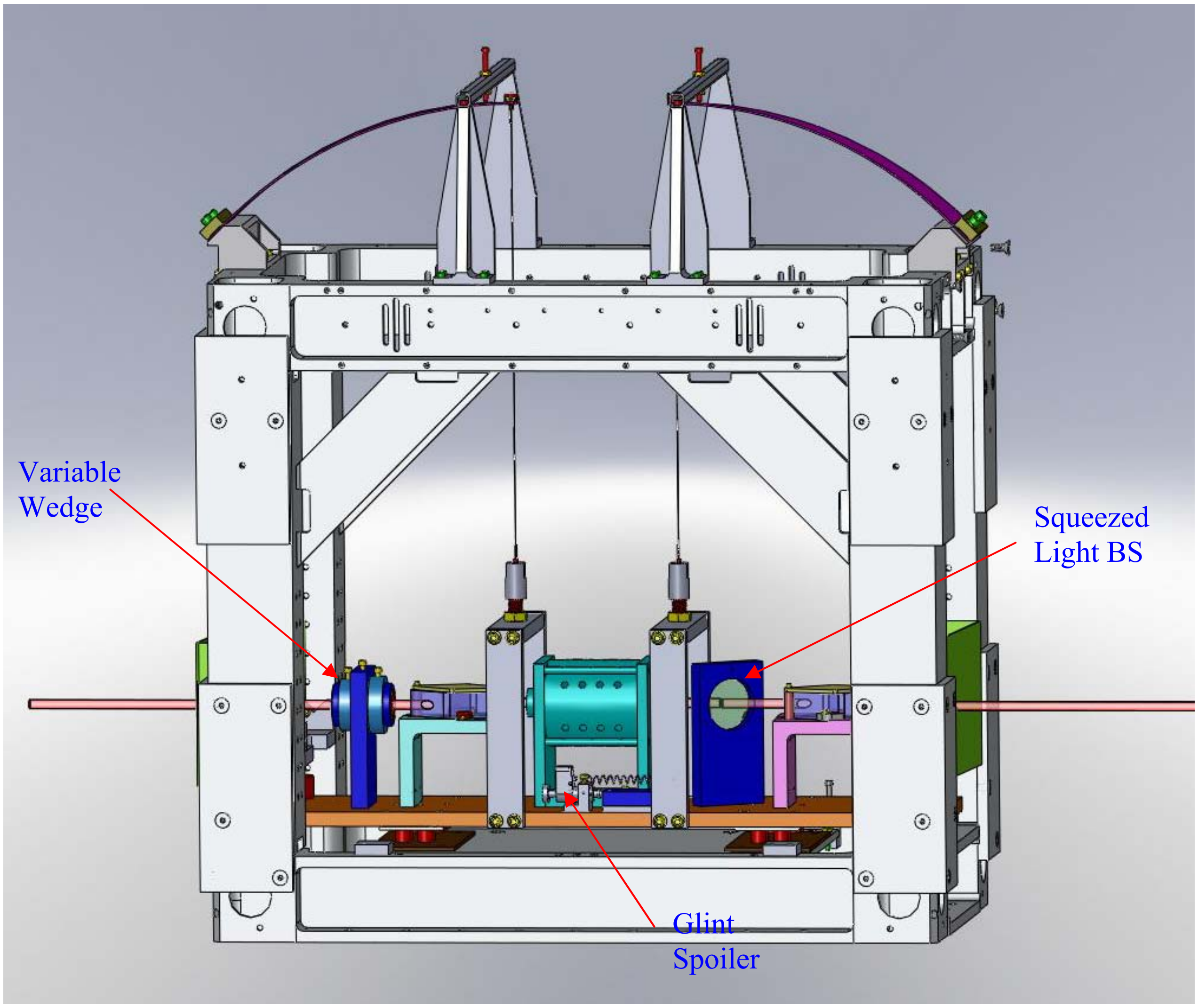

Figure 21: Suspended Faraday Isolator

Based on the recommendations from the reviewers, a four-wire suspension has been chosen for the final design. It removes the so called bridge structures, which connected the platform to the blades through a single wire as shown in the figure. Elimination of the bridge changes the suspension from a double pendulum into a single pendulum, simplifying the suspension itself and improving the attenuation at low frequencies. The resonant frequencies of the prototype double wire prototype, OFIS-Proto2, were measured and the results compare favorably with the analytical model of the suspension.

6.1 Blade Spring Design

The blade springs were designed and tested according to the following technical note: T0900324-v2.

- What dynamic analysis has been done of the payload? (i.e., resonant frequencies of the mounting plate and the objects mounted on it) How did you determine that the plate stiffness was adequate?

The internal modes were measured to be > 25 Hz. This was satisfactory for objects suspended from the ISI Stage "0". If this is not okay for the HAM ISI, a stiffer platform similar to the OMC aluminum platform will be designed.

- How is the payload balanced? What are the trim masses, how are they adjusted, etc? What are the mass and/or launch angle adjustments available to account for an 8% mass discrepancy (size of discrepancy between blade prediction and reality that is in line with suspensions blade analysis).

The height of the OFI optical table is adjusted by placing shims between the bottom of the suspension frame and the top of the HAM ISI table. The thickness of the shims will be determined after the ITM mirrors are installed and the beam height at the OFI is measured.
The payload is adjusted roughly parallel to the bottom surface of the suspension frame by turning the screw at the bottom of each suspension wire, to effectively change the length of the wire. This allows a range of adjustment of the height of the optical table of approximately +/- 1 mm. A fine adjustment of the tilt of the suspended payload is accomplished by sliding a pair of weights on each side of the payload.

- What is the conclusion of the eddy-current damping studies shown in T1000109? I.e., what level of damping are you designing for? How are the ECD plates positioned/aligned?

Based on measurements shown in T1000109, we estimate that a gap between a copper plate and the magnet face of 1.5mm with a total of 8 cylindrical magnets will be sufficient to reduce all the resonance quality factors to <30.. The magnets 3/4" diameter by 1/2" height with a nominal strength of ?? Tesla will be grouped in pairs and secured beneath the suspended table at the four corners. The damping measurement result should be valid for the new OFI suspension prototype (OFIS-Proto2).

The copper ECD plates are directly mounted to the suspension frame. The gap distance is coarsely set with the length of the suspension's wires and a balance mass, and fine adjusted using a sliding variable mass on the platform.

- What is the design for earthquake and transporting stops?

The suspended optics table can be rigidly fastened to the support frame by tightening the screws that pass through clearance holes in the table.

- What is the interface between the (OMC) suspension structure and the blade launch assembly?

The support bracket is attached to the existing mounting holes in the OMC suspension frame. The flat blade spring is clamped to the support bracket at a launch angle of 45 deg.

7 Assembly, Installation and Alignment.

- Where are you planning on assembling the isolators?

How are the items on the suspended platform positioned/adjusted?
All the items are attached via bolts through the bottom of the platform. The items are nominally in the proper beam line position. However; a slight amount of lateral movement is possible due to the oversized clearance holes.

Are you going to be shipping any assemblies where alignments will need to be maintained?
The Brewster's polarizing prisms are held in place by spring clamps and will not tolerate a high G-load impulse. Therefore, the optical platform will be populated with optics in a clean room at the sites. The remainder of the OFI can be cleaned and pre-assembled either at CIT and shipped to the sites, or cleaned and assembled at the sites.

Section 14 of T1000181 is blank; please tell us what you have planned here. What installation fixtures will be developed?

Fabrication:
The optical platform will be populated with optics in a clean room at the sites, aligned and tested. The remainder of the OFI can be cleaned and pre-assembled either at CIT and shipped to the sites, or cleaned and assembled at the sites.

Installation:
The OFI will be installed on the HAM ISI table by using a chamber door installation arm, with an installation procedure similar to that of the OMC.

Test Schedule:
The optical platform will be aligned and tested for extinction ratio and transmissivity in a clean optics lab at the sites. The alignment procedure is described in T000083-01 COS Faraday isolator alignment.
The aligned optical platform can be temporarily stored in a clean environment until it is needed for installation in the HAM chamber.

Installation Alignment.
How will the units be aligned in installation?
The OFI will be positioned on the HAM ISI table by means of locating templates.
A transparent cross-hair target will be temporarily placed in a holder at the entrance to the OFI on the optical centerline. The support structure will be shimmed until the PSL laser beam is centered on the target. A second cross-hair target will be temporarily placed in a holder at the exit of the OFI on the optical centerline. The OFI will be shifted laterally on the ISI table until the PSL beam is lines up with the cross hairs. Then, the optical table will be tilted by moving balance weights on the table until the PSL beam passes through the center of the OFI, defined by the cross hair targets.

What is the tolerance on the angular alignment?

There is no data available from the manufacturer. However, an analysis was done to estimate the change in Faraday polarization rotation as a function of input angle. The results are shown below. The path length change through the TGG crystal as a function of input angle is given by

$$\Delta_L(\theta_i) := L\cdot\left(\frac{1}{\cos(\theta_i)} - 1\right)$$

Where, L is the length of the crystal.
If the magnetic field is assumed to be constant, independent of input angle, the phase rotation angle of the polarization vector after a double pass through the isolator is given by

$$\phi_F(\theta_i) := \frac{\pi}{2}\cdot\left(1 + \frac{2\cdot\Delta_L(\theta_i)}{L}\right)$$

The reverse transmissivity through the input polarizer is given by

$$T(\theta_i) := \sin\left(\phi_F(\theta_i) - \frac{\pi}{2}\right)^2$$

The input beam angle can vary by +/- 0.14 radians, which is +/- 8.5 deg, and still meet the 1000:1 extinction ratio requirement.

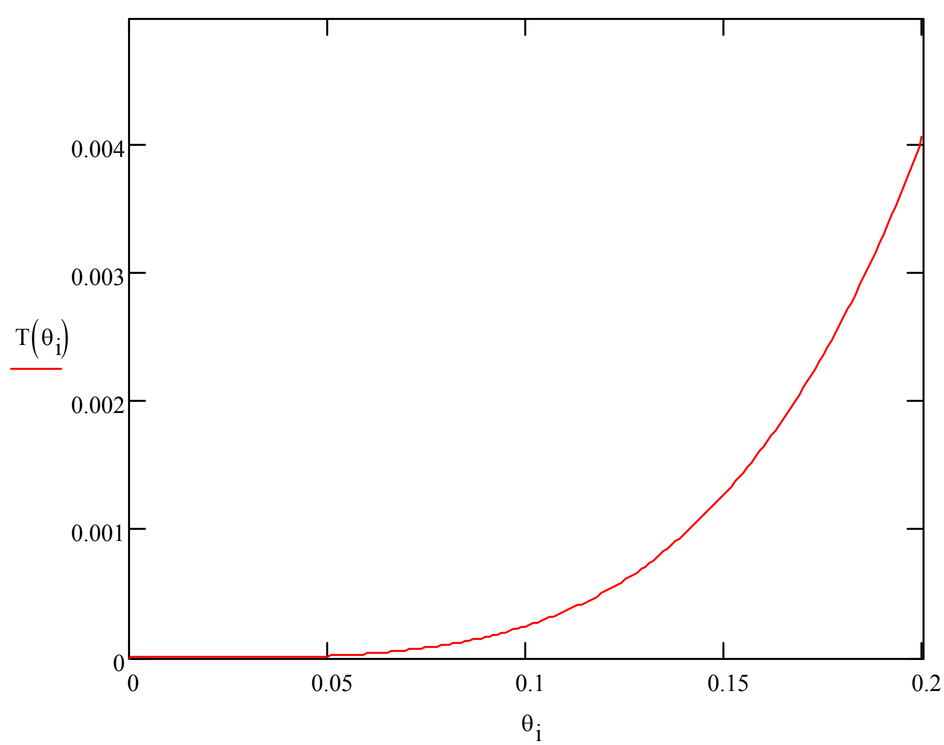

Figure 22: Faraday Isolator Extinction Ratio as a Function of Input Beam Angle, in radians.

In particular how do you ensure alignments of assemblies D0900623 and D0900570 with respect to all else?
The blade clamp assembly, D0900570, is rigidly mounted to the suspension frame, which is rigidly mounted to the HAM ISI. The optical platform hangs stably from the blade springs, which do not creep during a reasonable time interval. As long as the ISI table does not move or rotate, the OFI will stay in alignment.

Since there is no active control of the isolator position, show us what you have done to analyze alignment drifts.
There are no provisions to correct for motions of the underlying HAM ISI table. The largest H2 beam of diameter (@ 1/e^2) = 5.6 mm will wander within the 20 mm clear aperture of the OFI.

Spares: tell us the spares plan, more explicitly than what is in 12.6 of T1000181 (e.g. are they any fragile components that should have multiple spares?).
One complete OFI is available for spare parts.

Blades: Is the blade material on order?

The blade material has not been ordered. We have enough material on hand to make the blades. However, it would require being ground to the right thickness.

Blade springs should be made at 1.5x required number.

The experience to date with the flat maraging blade springs is that the actual load was within 10% of the design load. We are providing a 10% balancing mass to handle this 10% uncertainty. In addition, the bottom wire attachment provides an adjustment screw to change the height of the optical table. We don’t plan on making more than one extra set of blades.

8 Comments on the documentation.

The following comments are made on the documentation. They can be addressed as the documents are revised and finalized. They may also be addressed at the review meeting, as deemed necessary or worthwhile by the design team.

Note: somewhere in the documentation (T1000181 is probably a good choice), make it clear that this review does not include the suspension support structure, as this has already been reviewed for the OMC suspension.

This has been added in Sec. 5.1.1 of T1000181-v2.

T1000181-v1:

1. Table 1. Units need to be added to the parameters. Faraday BRDF: there are several values of BRDF given in the various documents and it is often not clear why or what is being used; is the value given here the one actually being used? If so, give the source.

Done

2. Delete empty sections: 1.6; 1.8.2; etc. Delete large empty spaces on many of the pages.

Will be Done

3. Table 4. Clarify how the scattered light power number is derived. Is this number actually used in the noise calculation?

This has been added in Sec. 5.3 of T1000181-v2.

4. 5.3.2. Are the isolation measurements on the iLIGO Faradays documented? If so, please give dcc link.

The referenced document includes a copy of a page from a lost notebook that gives the extinction ratio of one of the iLIGO OFIs. Presumably the documentation for the other iLIGO OFIs are in the elog during the installation period of iLIGO in 1999.
https://dcc.ligo.org/DocDB/0003/T000083/001/T000083-01_COS_Faraday_isolator_alignment.pdf

The EOT test report dated 3/23/99 gives the measured isolation ratios for the three Faraday Isolators as: 34 dB, 35 dB, and 36 dB.

7.1.1.4. Number is wrong: the beam diameter at the output of the SRM is 4.2 mm for the straight interferometers.

Correction was made

5. 12.4. List the elements of the OFI that are not interchangeable.

The Brewster's calcite polarizers must be kept together as matched pairs. The blade spring's stiffness may vary within 10% so that the balance weights and wire lengths may have to be matched to the particular blade spring. All other components are interchangeable.

6. 12.5. Please list assembly fixtures that exist.

No assembly fixtures exist.

7. 12.8 and 16. Why is 12.8 Qualification N/A? You give some qualifications in sec 16, so it's clearly not N/A. Please clean up this documentation.

For vacuum service, all materials are UHV qualified per E960050 and cleaned per qualified procedures in E960022.

The scattered light noise properties of the OFI will be qualified by 1) using measured BRDF properties of the scattering surfaces or similar surfaces, 2) measuring the motion transfer functions of the OFI suspension and the seismic motion of the HAM ISI, and 3) using the scattered light calculations to analyze the resulting scattered light displacement noise.

The extinction ratio and the transmissivity of the OFI will be qualified to meet the requirements by measuring the extinction ratio and transmissivity during the pre-alignment of the OFI before installation.

8. The document should contain a mass properties table

Mass properties table added in T1000181-v2 section 5.2.

Table 6: Mass Properties

Suspension frame, lb	59.6
Non suspended items, lb	15.9
Suspended items, lb	23.1
Total mass, lb	98.6

.

9. Sec 16. There is a large overlap between this section and T1000192. This makes it unclear as to what the real source is meant to be. Either: include everything that is in T1000192 in T1000181, and remove the former from the document set; or, refer to T1000192 for details for test plans, but otherwise delete this section.

T1000181-v2, section 16 was changed as follows:

"This section includes all of the examinations and tests to be performed in order to ascertain that the fabricated SLC elements conform to the requirements in section 3.

See T1000192-v2 for the details."

T1000194:

1. Replace Rich Riesen with David Nolting, LIGO Lab Safety Officer, on the signature sheet; remove Bill Tyler from the signature sheet.

Done

2. What mechanical lifting devise will be used to assist in the installation process?

HAM Installation Arm

3. Please add in the matrix, that the lifting device be inspected prior to use to ensure safe operation, and people trained in its use.

Done

T1000192:

1. 2.1: Elaborate on the following items for vendor tests: What tests? What data points will be reviewed as acceptance criteria? Will we participate in or observe the testing? We should ensure the vendor supplies us in advance with their testing plan for our review, approval.

I added the following explanation to T1000192-v2, sec 2.1:

8.1 Vendor Tests

8.1.1 Faraday Rotator Test

LIGO will not witness the tests. The vendor will certify that they have complied with the tests, and will provide calibration certification for the test equipment, as appropriate. The vendor will supply the following test documentation: 1) Interferogram of transmitted wavefront across the clear aperture, 2) Optical transmissivity through the clear aperture, 3) Extinction ratio for orthogonal polarizations through the clear aperture.

The acceptance values for the tested quantities are detailed in E1000116-v2.

8.1.1.1 Visual Surface Inspection Test

Both faces of the TGG crystal shall be free of visible stains and surface defects when the window is illuminated with a high-intensity light source and viewed in a darkened environment with the unaided eye.

8.1.1.2 Extinction Ratio Test

Extinction ratio between crossed polarizers for orthogonal polarizations shall be measured, using the test light source.

8.1.1.3 Optical Transmissivity Test

Optical transmissivity through the clear aperture shall be measured with the test light source.

8.1.1.4 Test Light Source

A collimated laser beam of 1064 nm wavelength and > 9.0 mm Gaussian beam waist diameter measured at the 1/e^2 power diameter shall fill the clear aperture when making transmissivity and extinction ratio measurements.

8.1.1.5 Wavefront Distortion Test

The transmitted wavefront distortion over the clear aperture shall be measured at 632.8 nm wavelength with an appropriate interferometer.

8.1.2 Brewster's Prism Polarizer & Half Wave Plate

LIGO will not witness the tests. The vendor will certify that they have complied with the tests, and will provide calibration certification for the test equipment, as appropriate. The vendor will supply the following test documentation: 1) Interferogram of transmitted wavefront across the clear aperture, 2) Optical transmissivity through the clear aperture, 3) Extinction ratio for orthogonal polarizations through the clear aperture.

The acceptance values for the tested quantities are described in the product catalog of Karl Lambrecht Corp.

8.1.2.1 Visual Surface Inspection Test

All faces of the optics shall have equal to or better than a 40-20 scratch dig surface quality over the clear aperture. The optical substrates shall be free of visible bubbles.

8.1.2.2 Extinction Ratio Test

Extinction ratio between crossed polarizers for orthogonal polarizations shall be measured, using an appropriately polarized coherent light source.

8.1.2.3 Optical Transmissivity Test

Optical transmissivity through the clear aperture shall be measured with an appropriately polarized coherent light source..

8.1.2.4 Wavefront Distortion Test

The transmitted wavefront distortion over the clear aperture shall be measured at 632.8 nm wavelength with an appropriate interferometer.

8.1.2.5 Retardation of Half Wave Plate Test

The optical phase retardation of the half wave plate shall be measured.

2. All other tests: We will need to specifically call out the results fields and acceptance parameters for each test. All tests should be recorded in ICS as a test record assigned to a component or assembly in the system.

The following revision was made to T1000192-v2, sec 2.2:

8.2 LIGO Tests

AOS will conduct final performance tests of the assembled OFI to verify that the OFI meets the LIGO requirements.

8.2.1 Output Faraday Isolator Pre-alignment Test

The OFI will be pre-aligned using the procedure described in T000083-01 and tested prior to installation in the chamber.

The acceptable values of the tested parameters are detailed in E1000116-v1, sec. 3.1

The following parameters will be measured and recorded in ICS as a test record assigned to the OFI: 1) Optical transmissivity in the forward direction, and 2) extinction ratio in the backward direction. Wavefront distortion of the OFI assembly will not be measured.

The total wavefront distortion of the OFI assembly will be calculated from the measured values of the individual in-line components. The acceptance criteria for wavefront distortion is specified at the component level.
The acceptable transmission in the forward direction is calculated from the acceptable values of the individual components. The minimum allowed extinction ratio is specified in E1000116-v1, sec. 3.1.

3. 2.1.1.1 High Intensity Light Sources: Do we have specific requirements for the light source intensity, etc? When you say free of, I have noted that with regards to Core Optics and Aux Optics, free of means nothing larger than some value or less than a count in a sq. area. Is this really free of or is there a size/count limit?

The High Intensity Light Source used by the vendor is an AmScope series Haloid Cold Light Source. It is a 150W power lamp. It has a dial to turn up or down the intensity.
The surfaces are viewed/inspected with the bright light shining at the end surface but with a 15 to 20 degree tilt as to not hurt the viewers eyes. Also the scratch dig spec is measured with the unaided eye using a professional comparison tool. The scratch/dig tool is used during incoming inspection and after final cleaning if there is a surface flaw noticed. They use a spec of nothing larger than scratch 10/dig 5

4. 2.1.1.4, test light source – why is the beam size so big? Is this really what you want?

The test light source is used to measure the extinction ratio and the optical transmissivity. The large size is to fill the clear aperture.

5. 2.2.2: What is the Q value these must meet suspended?

The stray light calculations were based on the OFI suspension having a Q = 100

6. How will the impulse test be done, with a small piezo hammer? Roving or fixed point? We should have a procedure for this test referenced.

The internal modes were determined by banging on the structure with a hammer and measuring the frequency spectrum with accelerometers placed on the suspended platform in 3 orthogonal directions.
The rigid body modes were determined by pushing on the suspended platform to excite the pendulum modes in the various degrees of freedom.

9 Comments on the drawings.

The following comments should be taken into account as the drawings are revised and finalized. They may also be addressed at the review meeting, as deemed necessary or worthwhile by the design team.

1) In general a 2nd pass of all drawings should be done once alignment understood from a dimensional / tolerance point of view

2) D0900136, what about dog clamps?

3) D0900570, is 2 1/4-20 screws enough why not use 3?

4) D0900570, should be stainless not silver plated as mating part D0900569 is alum

(refer to http://lhocds.ligo-wa.caltech.edu:8000/advligo/Fasteners for guidelines)

5) D0900566, 0.272 clearance hole seems large?

6) Finish missing on a lot of drawings, refer to E0900364 (will not repeat but applies to many)

7) Tolerance missing on some drawings

8) DCN numbers missing (again repeats on many drawings)

9) D0900569, think about heli-coils or oversize taps (applies to many many drawings, essentially everywhere a tapped hole is used, http://lhocds.ligo-wa.caltech.edu:8000/advligo/HeliCoils)

10) D0900588, what prep is used to ensure UNF can be used in clean conditions?

11) D0900541, are slots for adjustment if so how much do they offer?

12) D0900583, again oversize taps or heli-coils, see above (will not repeat but does appear on many drawings)

13) Screws in general should call out vendor and or part number (refer to http://lhocds.ligo-wa.caltech.edu:8000/advligo/Fasteners for guidelines)

14) What does overall suspension assembly weigh?

15) Do you have earthquake stops?

16) Can system be clamped for transport?

17) D0900579, round end screws don't exist you need to machine a n off the shelf screw

18) D0900579, structure is alum so screw should be stainless

19) D0900578, blind hole so call out vent hole required also oversize tap or heli-coil and finish call-out

20) D0901271, finish

21) D0900578, tapped hole and finish

22) D0900027, finish

23) D0900026, tapped hole and finish

24) D0900169, vent, tapped hole and finish

25) Several with finish, tapped hole, blind hole issues (refer to red-line set)

26) D0900015, no stock finish (applies to all stock call-outs and again tapped holes and finish

27) D0900624, D0900353, D0900440, blind holes? screws used, tapped holes?

28) D0901764, weight, range offered? finish cannot be 125 micro-inch, refer to E0900364

29) D0900441, no stock finish allowed

30) D0900352, D0900439, tapped hole again consider oversized or heli-coil

31) D0902754, are these ball slides approved?

32) D0902752, finish, blind hole needs vent and tapped hole needs thought on helicoil or oversized tap. .Also why 6-32 haven't seen this anywhere and it is very close to 8-32 which you use. Can you use 8-32 to make assembly easier?

Table 1. Status of Drawing Package [LIGO-T1000191-v1]

TYPE	DCC #	TITLE	STATUS	REMARKS
TOP ASSY	D0900136-v1	FARADAY ISOLATOR ASSEMBLY	I/C	DCN, Title Block, Spares
PRT	D0902846-xx	INPUT BAFFLE	I/C	Rev., DCN, Title Block
PRT	D0902845-xx	REFLECTION BAFFLE	I/C	Rev., DCN, Title Block
ASSY	D0901161-xx	EARTHQUAKE STOP ASSY	I/C	Rev., DCN, Title Block, BOM, Item #s
ASSY	D0900170-xx	EARTH CROSSBAR ASSY	Not Needed ?	
PRT	D0900168-v1	CROSSBAR PLATE	I/C	DCN, Title Block, parent = D0901161 ?
PRT	D0900169-v1	CROSSBAR SIDE	I/C	DCN, Title Block, parent = D0901161 ?
ASSY	D0900623-xx	FARADAY ISOLATOR TABLE ASSY	I/C	Rev., DCN, Title Block, BOM, Item #s
PRT	D0900015-xx	FARADAY ISOLATOR TABLE	DNE	
ASSY	D0900359-xx	WEDGE WINDOW HOLDER ASSY	I/C	Rev., DCN, Title Block, BOM
PRT	D0900356-xx	WEDGE SET SCREW #1 1/8-20 UN	I/C	Rev., DCN, Title Block
PRT	D0900355-xx	WEDGE ROTATING FIXTURE	I/C	Rev., DCN, Title Block
PRT	D0900357-xx	WEDGE WINDOW HOUSING	I/C	Rev., DCN, Title Block
PRT	D0900358-xx	WEDGE WINDOW PLATE HOLDER	I/C	Rev., DCN, Title Block, not stock thickness
ASSY	D0900615-x040	PRISM MOUNTING ASSY-RH	I/C	Rev., DCN, Title Block, BOM, Ref. Dim's
PRT	D0900620-xx	PRISM BLOCK-RH	DNE	

PRT	D0900618-xx	PRISM CLAMP	DNE	
PRT	D0900619-xx	PRISM POST .312 DIA	DNE	
PRT	D0900617-xx	PRISM KLC NO. K1063-4	DNE	
ASSY	D0900464-v1	Rotator 20mm 1064nm-VAC COMPATIBLE	I/C	Title Block
ASSY	D0900353-xx	HALF WAVE PLATE HOLDER ASSY	DNE	
PRT	D0900352-xx	HALF WAVE PLATE HOLDER	DNE	
ASSY	D0900440-xx	TFP POLARIZER PALTE ASSY	DNE	Title Typo, in BOM of D0900623
PRT	D0900439-xx	TFP POLARIZER PLATE	DNE	
ASSY	D0900614-x041	PRISM MOUNTING ASSY-LH	I/C	Rev., DCN, Title Block, BOM, Ref. Dim's
PRT	D0900166-xx	PICO MOTOR MOUNT BRACKET	DNE	
PRT	D0900165-x004	COUNTER MASS BLOCK	I/C	Rev, DCN, Title Block, not stock thickness
ASSY	D0900624-xx	TABLE HANGER ASSY	DNE	
PRT	D0900143-xx	WIRE LOWER BRIDGE	I/C	Rev, DCN, Title Block, ISO View, Bore Dim
PRT	D0900147-xx	WIRE LOWER PLATE	I/C	Rev, DCN, Title Block, ISO View
PRT	D0901764-xx	TABLE BALANCE WEIGHT	DNE	
PRT	D0900778-v1	MAGNET ATTACHMENT PLATE	I/C	Title Block, ISO View
ASSY	D0900570-xx	UP BLADE CLAMP ASSY	I/C	Rev, DCN, Title Block, Spares, BOM
ASSY	D0900586-xx	UPPER WIRE ASSEMBLY	I/C	Not Needed ?
PRT	D0900541-v1	UPPER BLADE	I/C	"Designer", parent = D0900570 ?
PRT	D0900588-v1	WIRE ADJUSTABLE ADAPTER	I/C	"Designer", parent = D0900570 ?
PRT	D0900582-v1	MUSIC WIRE SPLIT CLAMP 1	I/C	"Designer", parent = D0900570 ?
PRT	D0900583-xx	MUSIC WIRE CLAMP 2	I/C	Rev, DCN, Title Block, parent = D0900570 ?
PRT	D0900584-v1	UPPER MUSIC WIRE	I/C	"Designer", parent = D0900570 ?
PRT	D0900566-v1	UP BLADE CLAMP TOP	I/C	"Designer"
PRT	D0900569-v1	BLADE CLAMP PLATFORM	I/C	Title Block "Designer"
ASSY	D0900579-v1	BLADE GUARD ASSY	I/C	"Designer", BOM, Spares
PRT	D0901271-v1	BLADE GUARD CROSS PIECE	I/C	"Designer"
PRT	D0900578-v1	BLADE GUARD RISER	I/C	"Designer"
ASSY	D0900048-xx	MAGNET HOLDER ASSEMBLY	I/C	Rev, Title, DCN, BOM, Spares
PRT	D0900026-v1	MAGNET MOUNTING PLATE	I/C	"Designer"
PRT	D0901570-xx	MAGNETIC PLATE MOUNTING BACK BRACKET	I/C	Rev, Title Block, DCN
PRT	D0900027-v1	COPPER PLATE	I/C	DCN, "Designer"
PRT	D0901569-xx	MAGNETIC PLATE MOUNTING FRONT BRACKET	I/C	DWG #, Rev, Title Block, DCN, Dim's
ASSY	D0900655	STRUCTURAL WELDMENT ASSY, OMC	Not Part of This Review Package	

"I/C" = Incomplete

"DNE" = Does Not Exist in DCC

In general, the following comments apply to all drawings and assemblies:

- notes on drawings should include content described in Section 3.1 of LIGO-E0900364-v2

- hardware for each assembly must be identified by vendor part number, and be selected from an approved vendor that supplies certificates of compliance (COC's)